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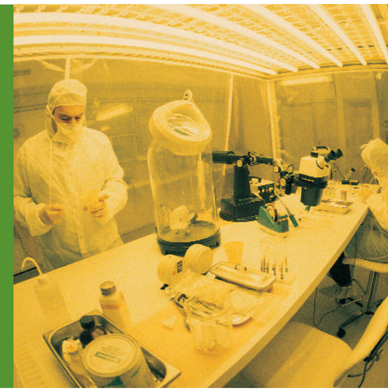

GROWING SOUTHERN ARIZONA'S BIOSCIENCE SECTOR:

A REGIONAL ROADMAP

PREPARED FOR:
Southern Arizona Leadership Council
with financial support provided by the Flinn Foundation

PREPARED BY:
Battelle
Technology Partnership Practice

November 2006

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List of Abbreviations

ABA	Arizona BioIndustry Association
ABRC	Arizona Biomedical Research Commission
AHSC	Arizona Health Sciences Center
ARL	Arizona Research Laboratories
ASU	Arizona State University
BIO	Biotechnology Industry Organization
BLS	Bureau of Labor Statistics
BTEC	Biomanufacturing Training and Education Center
C-Path	Critical Path Institute
CEO	chief executive officer
CFO	chief financial officer
CIS	Center for Insect Sciences
COO	chief operating officer
CTSA	Clinical and Translational Science Award
DNA	deoxyribonucleic acid
FDA	U.S. Food and Drug Administration
FY	fiscal year
HTG	High Throughput Genomics, Inc.
IP	intellectual property
IPO	initial public offering
IRB	Internal Review Board
IT	information technology
LQ	location quotient
MSA	metropolitan statistical area
NBER	National Bureau of Economic Research
NIH	National Institutes of Health
NSF	National Science Foundation
QCEW	Quarterly Census of Employment and Wages
R&D	research and development
SALC	Southern Arizona Leadership Council
SBIR	Small Business Innovation Research Program
STTR	Small Business Technology Transfer Program
TGen	Translational Genomics Research Center
TPP	Battelle's Technology Partnership Practice
UA	University of Arizona
UI	unemployment insurance
UMC	University Medical Center
VA	Veterans Affairs

Executive Summary

INTRODUCTION

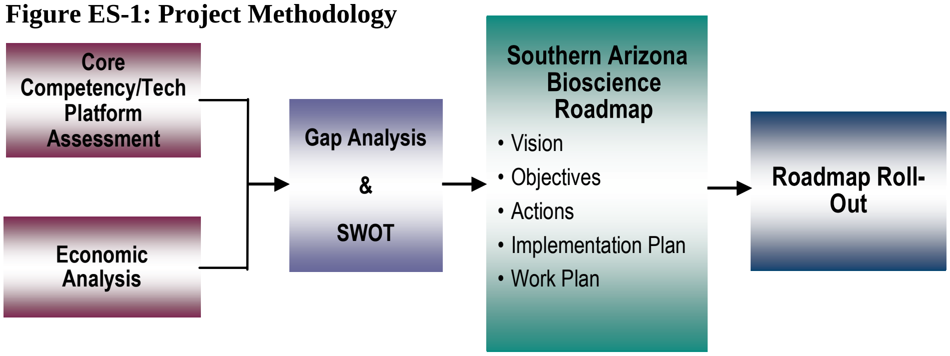
In 2002, public and private leaders in Arizona committed to making the investments necessary to position Arizona as a leading center for the biosciences. The *Arizona Bioscience Roadmap*[1] called for building the state's infrastructure around selected technology platforms, growing a critical mass of bioscience firms, and offering a business climate and environment to support bioscience enterprises. Significant progress has been made in building an environment in Arizona that is supportive of bioscience enterprises.

Much of Arizona's existing bioscience activity—both its industry base and research base—is located in Southern Arizona. The region is home to the University of Arizona (UA), which is the key driver of bioscience research in the state, and contains both well-established bioscience companies, such as MRI Medical Manufacturing and Research Inc., SEBRA, Sonora Quest Labs, and Ventana Medical Systems, and smaller, startup and emerging companies. The Southern Arizona region, under the leadership of the Southern Arizona Leadership Council, has developed this regional bioscience roadmap to complement the statewide effort and to focus on specific challenges and opportunities facing Southern Arizona. This Roadmap, developed with support provided by the Flinn Foundation and assistance provided by Battelle, lays out a pathway to accomplish the following vision:

> *Southern Arizona is one of the nation's recognized bioscience centers, driven by its strengths of a talented workforce, a cutting-edge research university, and a global center for bioscience innovation. Its civic leaders help drive the bioscience economy, mobilizing leadership committed to collaboration, results, and economic growth.*

This Regional Roadmap was developed with guidance and input from the region's research institutions, bioscience companies, and other public and private leaders. The Battelle project team collected and analyzed data on Southern Arizona's bioscience industry and research bases and interviewed academic, research, business, and civic leaders to develop an understanding of the region's existing bioscience research strengths and capabilities and to gather input on the types of investments needed to enable Southern Arizona to become a well-recognized regional bioscience center. Figure ES-1 displays the project methodology.

Figure ES-1: Project Methodology



[1] *Platform for Progress: Arizona's Bioscience Roadmap*. Prepared for the Flinn Foundation by Battelle Technology Partnership Practice. December 2002.

SOUTHERN ARIZONA'S BIOSCIENCE INDUSTRY BASE

Southern Arizona's bioscience sector is young, but has experienced rapid growth in total and across key subsectors. The bioscience sector (defined here as including agricultural feedstock and chemicals; drugs and pharmaceuticals; hospitals; medical devices and equipment; and research, testing, and medical laboratories) added nearly 1,000 jobs, an increase of 7.1 percent between 2001 and 2004 in the Tucson metropolitan area. (These data include only private sector employment, employment at the University of Arizona is not included.) Southern Arizona bioscience employment grew about 1.5 times as fast as the sector nationally (up 4.8 percent).

The largest bioscience subsector, hospitals, has a strong and growing regional presence. The premier nature of bioscience research at the UA and the University Medical Center (UMC) are tremendous strengths for the Southern Arizona bioscience base. Nearly 13,000 individuals were employed in the hospitals subsector in Southern Arizona in 2004.

Southern Arizona's nonhospital bioscience sector is modest in size, but growing rapidly. The nonhospital sector employs nearly 2,000 individuals across 112 business establishments. Nearly all these workers are within the medical devices and equipment and research, testing, and medical laboratories subsectors. While the nonhospital biosciences overall have a modest location quotient (LQ)—0.65 in 2004—the sector is growing at a rapid pace.[2] ***Since 2001, the Southern Arizona nonhospital biosciences have seen employment rise by 21.9 percent, compared with just 0.9 percent nationally***. This strong employment growth boosted the regional LQ as the concentration of bioscience workers in Southern Arizona increased relative to the nation.

The research, testing, and medical laboratories subsector is the fastest growing and the largest among the nonhospital subsectors. The subsector employed 1,100 in the Southern Arizona in 2004. The region added more than 300 jobs during the 2001 to 2004 period, a gain of 45.6 percent, much faster than the 7 percent growth of this subsector at the national level. Research, testing, and medical laboratories in Southern Arizona posted a 1.07 LQ in 2004, making it a concentrated industry subsector. ***In Battelle's 2006 national report for the Biotechnology Industry Organization (BIO), the Tucson metropolitan area ranked 28th among 72 large metropolitan areas based on its LQ in the research, testing, and medical laboratories subsector in 2004***.3

Manufacturers of medical devices and equipment have a significant presence in Southern Arizona. Firms engaged in the production of medical devices, supplies, and instruments employ more than 800 in Southern Arizona, up slightly (1.5 percent) since 2001. Nationally, the subsector shed jobs during the early 2000s—employment declined by 3 percent and the number of U.S. establishments was essentially flat. Southern Arizona added to its medical device establishments; in 2004, there were 57 total.

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[2] Location quotients are a standard measure of the concentration of a particular industry in a region relative to the nation (reference area). The LQ is the share of total regional employment in the particular industry divided by the share of total industry employment in the nation (reference area). An LQ greater than 1.0 for a particular industry indicates that the region is relatively concentrated, whereas an LQ less than 1.0 signifies a relative underrepresentation. An LQ greater than 1.20 denotes employment concentration significantly above the national average. Throughout this report, LQs are used to report regional industry concentrations relative to the U.S. as a whole. The minimum concentration threshold for declaring a regional specialization is a matter of judgment and varies somewhat in the relevant literature. In this analysis, regional specializations are defined by LQs of 1.20 or greater.

[3] *Growing the Nation's Bioscience Sector: State Bioscience Initiatives 2006.* Prepared for BIO by Battelle Technology Partnership Practice and SSTI, April 2006. The full report can be accessed online at http://www.bio.org/local/battelle2006/.

The biosciences provide well-paying jobs for Southern Arizona's residents. In 2004, the average bioscience worker in Southern Arizona earned $40,004, which is 22 percent (or $7,227) more than the $32,777 for the average worker in the private sector. Average wages in the nonhospital bioscience sector tend to be higher than average hospital wages. In 2004, the average annual salary in the nonhospital sector was $47,476, nearly $15,000 more than the private sector average (Table ES-1).

Table ES-1: Average Annual Wages in Southern Arizona for the Biosciences, 2004

Major Southern Arizona Industry	2004 Avg. Wages
Drugs & Pharmaceuticals	$61,333
Research, Testing, & Medical Laboratories	$58,140
Total Nonhospital Biosciences	$47,476
Total Biosciences	$40,004
Hospitals	$38,845
Agricultural Feedstock & Chemicals	$37,040
Medical Devices & Equipment	$33,532
Total Private Sector	$32,777

Source: Battelle calculations based on Bureau of Labor Statistics, Quarterly Census of Employment and Wages program data from IMPLAN.

Southern Arizona accounts for a large share of Arizona's overall bioscience sector. The region has an influential role in driving state bioscience trends and a unique opportunity to leverage its research base to further build its bioscience industry base.

SOUTHERN ARIZONA'S BIOSCIENCE RESEARCH BASE

The UA is both the leading statewide bioscience research driver as well as the principal driver of bioscience research in Southern Arizona. At the statewide level, UA accounts for 59 percent of all university life sciences research in Arizona and 62 percent of National Institutes of Health (NIH) funding to Arizona—and is home to the only medical school, pharmacy school, and agricultural school in the state. Almost half of the university's research enterprise is in the life sciences, with medical sciences accounting for $100 million in R&D in 2004. In addition, the university has strong bases in the biological sciences ($76.6 million) and the agricultural sciences ($66.5 million).

Life sciences have been a key generator of growth in the UA's research base in recent years. From 1997 to 2004, life sciences research grew by 77 percent, compared with 68 percent overall growth in the university's research base. In the aggregate, 50 percent of the $193 million gain in research activity at the UA resulted from growth in the life sciences.

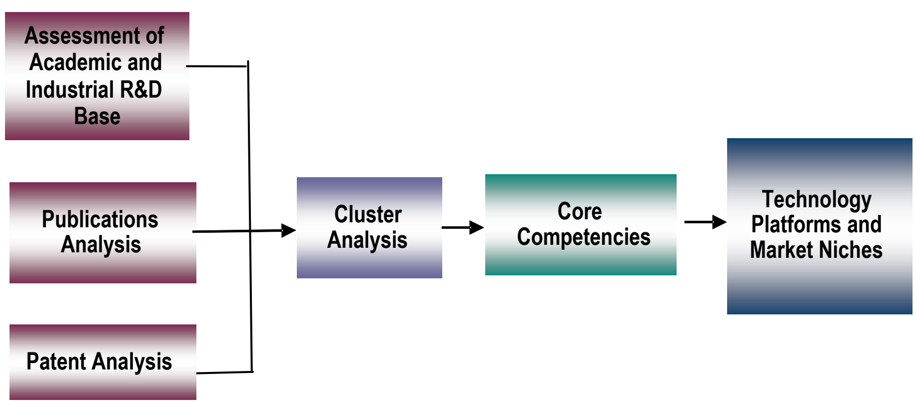
In medical sciences and agricultural sciences, the UA outpaced overall U.S. university research growth from 1997 to 2004. Medical sciences research at UA rose by 108 percent, compared with growth of 103 percent nationally. In agricultural sciences, where the UA ranks 13th nationally, the relative growth has been even more impressive, with UA advancing by 60 percent compared with 37 percent growth nationally in university research from 1997 to 2004. In closely related fields of psychology and chemistry, UA also made substantial gains of 124 percent and 101 percent, respectively, which outpaced national growth in those fields.

Overall, however, the UA is still playing catch-up in the biosciences. While UA is growing its intensity in bioscience research as a percent of total university research—from 48 percent in 1997 to 53 percent in 2004—it is still below the national average of 60 percent. Also, despite significant gains in overall medical research funding, it is still not keeping pace in NIH research funding—the gold standard of biomedical research funding—with UA's share of national NIH extramural funding dropping from 0.57 percent in 1997 to 0.46 percent in 2005.

Bioscience Technology Platforms for Southern Arizona

The biosciences present so many opportunities for the future that it is extremely important for a state or region to understand where its opportunities will lie within a very broad universe of bioscience disciplines, opportunity areas, and possibilities. To identify the specialized niches for Southern Arizona, Battelle employed a methodology that uses the "marketplace" of academe, including peer-driven recognition systems, e.g., publications, citations, and federal fund awards, along with extensive number of interviews with research leaders, to identify targets of opportunity (Figure ES-2). Battelle used its proprietary software, *OmniViz*™, to examine the presence of research "clusters." Using this unique text analysis tool, along with detailed faculty interviews and a review of publications strengths and funding levels, Battelle documented Southern Arizona's research core competencies and recommended associated technology platforms, which can form the basis for the future growth of Southern Arizona's bioscience sector.

Figure ES-2: Methodology to Identify Technology Platforms and Market Niches



The areas of greatest opportunity for developing technology platforms are those in which a region has

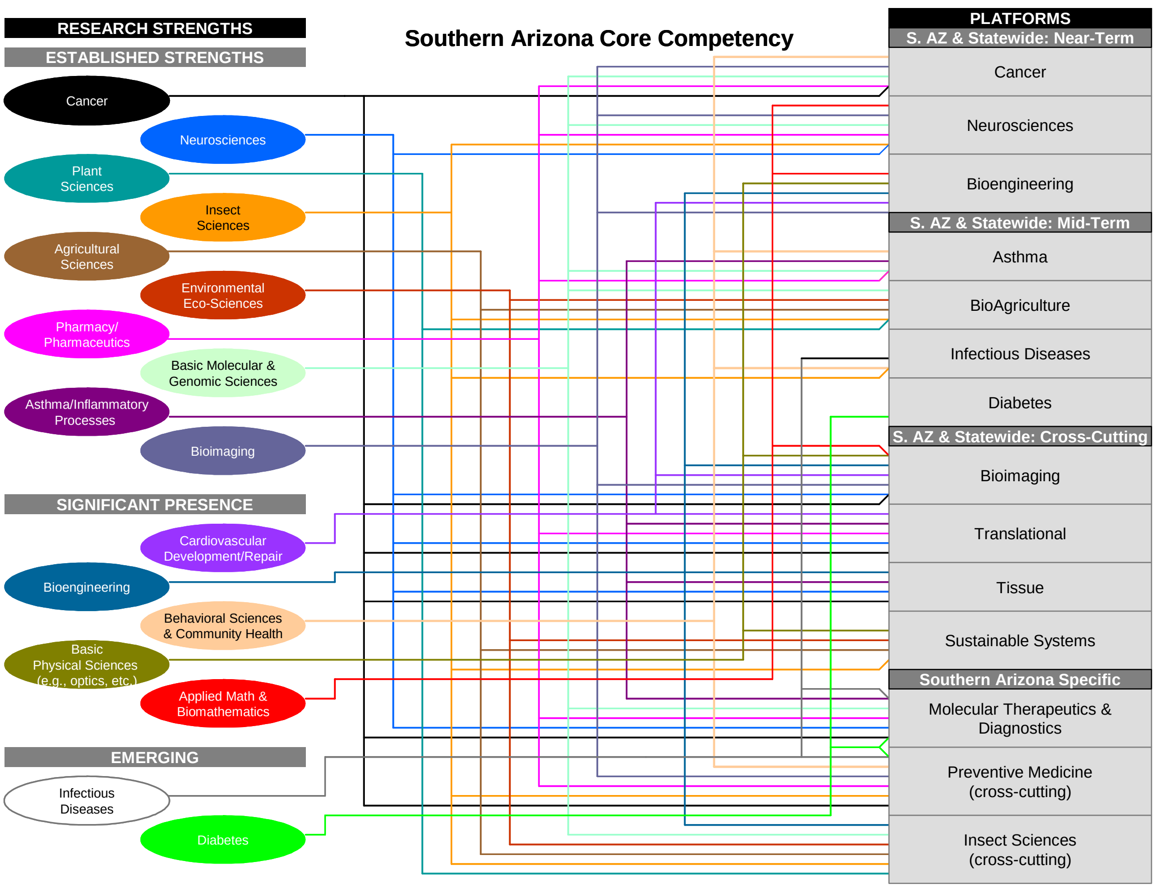
- Existing research strengths;
- Bases of commercial activity emerging or established within the region with genuine opportunity to create a base in the near future;
- Distinct opportunities to leverage the region's comparative advantages to create competitive marketplace advantages;
- Significant product market potential; and
- Links to, or reinforcements of, other bioscience strengths and core research competencies, thereby helping to enhance other fields as a platform expands.

The Battelle team in its 2006 update of the Arizona's core competencies and technology platforms in the biosciences validated the same near-term and mid-term platforms first identified in 2002, as well as the cross-cutting areas in which universities, teaching hospitals and medical centers, and research institutions have been working since 2002. But, Battelle also identified the following three technology platforms unique to the region that build upon Southern Arizona's research core competencies and can be a source of innovative technologies and products for Southern Arizona's economy:

1. Molecular Targeted Therapeutics and Diagnostics
2. Preventive Medicine
3. Insect Sciences.

Figure ES-3 shows the relationship between Southern Arizona's research strengths and both the state's and Southern Arizona's technology platforms.

Figure ES-3: Relationship Between Southern Arizona's Research Strengths and Arizona and Southern Arizona Technology Platforms



SITUATIONAL ASSESSMENT

It is clear that Southern Arizona has an emerging industrial base and a strong research base on which to continue to build its bioscience economy, and strategic areas for future development have been identified. But, this region is not the only region seeking to grow its bioscience sector. States and regions across the United States are investing significant resources in the biosciences.

To succeed, Southern Arizona must build upon its competitive advantages as a location for bioscience companies and address any competitive disadvantages. The Battelle project team interviewed public and private leaders, bioscience company CEOs, entrepreneurs, venture capitalists, government officials and service providers to get their assessment of Southern Arizona as a location for bioscience development. The text box at right summarizes the region's key competitive advantages and the challenges that will need to be addressed to accelerate the growth of Southern Arizona's bioscience economy.

Competitive Advantages

- University of Arizona
  - R&D Base
  - Students and Graduates
  - Highly rated Entrepreneurship Program
- Entrepreneurial environment
- Core base of bioscience start-ups and established companies
- Quality of life that appeals to many talented individuals
- Base of experienced retirees

Challenges

- Retaining faculty and staying at the cutting edge of bioscience research
- Not enough being done to commercialize technology generated by U of A
- Small clinical science base, small medical school
- Insufficient interaction between large and small bioscience companies and between companies and the U of A
- Perception of quality of K-12 education
- Insufficient sources of capital

There was general agreement that Southern Arizona has three differentiating drivers on which to build its bioscience base:

1. **A culture of entrepreneurship.** Southern Arizona has a strong history of creating bioscience-driven firms. Some of these have been developed around technologies developed by UA faculty and researchers, particularly those associated with the Cancer Center; others were created when some of these initial firms generated additional spin-off companies. The region has identified successes such as Ventana and Sanofi-Aventis, among others, something few other regions in the country have to the extent that this region does.
2. **A deep research base.** UA's and UMC's strengths in the core competencies and technology platforms identified in this report show how critical UA is to the state's and region's research enterprise. A pioneering UA has emphasized interdisciplinary research and partnerships since the early 1970s and is ideally positioned to respond to the opportunities and challenges that face the biosciences.
3. **A strong quality of life.** The region's quality of life attracts and retains talent, researchers, and enterprises. Reasonable costs of living, relatively smooth traffic flow, cultural amenities, and other factors are all rated positively by residents of Southern Arizona.

To take advantage of these drivers, several **strategic directions** are suggested, based on the strengths and opportunities found in the region:

- Ensure that UA continues to be Arizona's strong research engine in the biosciences, particularly in those platforms of strength or emerging strength identified in this report.
- Increase the region's ability to capture innovation from this research base and its existing bioscience enterprises and other industries in order to become a strong center of technology entrepreneurship, which can translate into new firms, increased wealth, and high-wage jobs.
- Focus the region's economic development approach on recruiting bioscience-related firms around the region's strengths in its technology platforms and its existing industry base.
- Employ the region's civic leadership to recognize and engage the entire population in a technology-driven economic future, a key component of which is the biosciences. The biosciences represent a technology convergence opportunity as well, building on the region's strengths in optics and related information technology areas.

STRATEGIES AND ACTIONS

The strategies proposed for Southern Arizona focus on leveraging the region's assets—its talent base, research base, and its core of established companies—to attract, create, grow, and strengthen further its critical mass of research in focused areas, while at the same time continuing to achieve a critical mass of bioscience firms. The region's bioscience industry base is growing, but it is still small. Specific strategies include the following:

Strategy One: Continue to build Southern Arizona's research strengths around bioscience technology platforms.

Strategy Two: Continue to build a critical mass of bioscience firms in Southern Arizona.

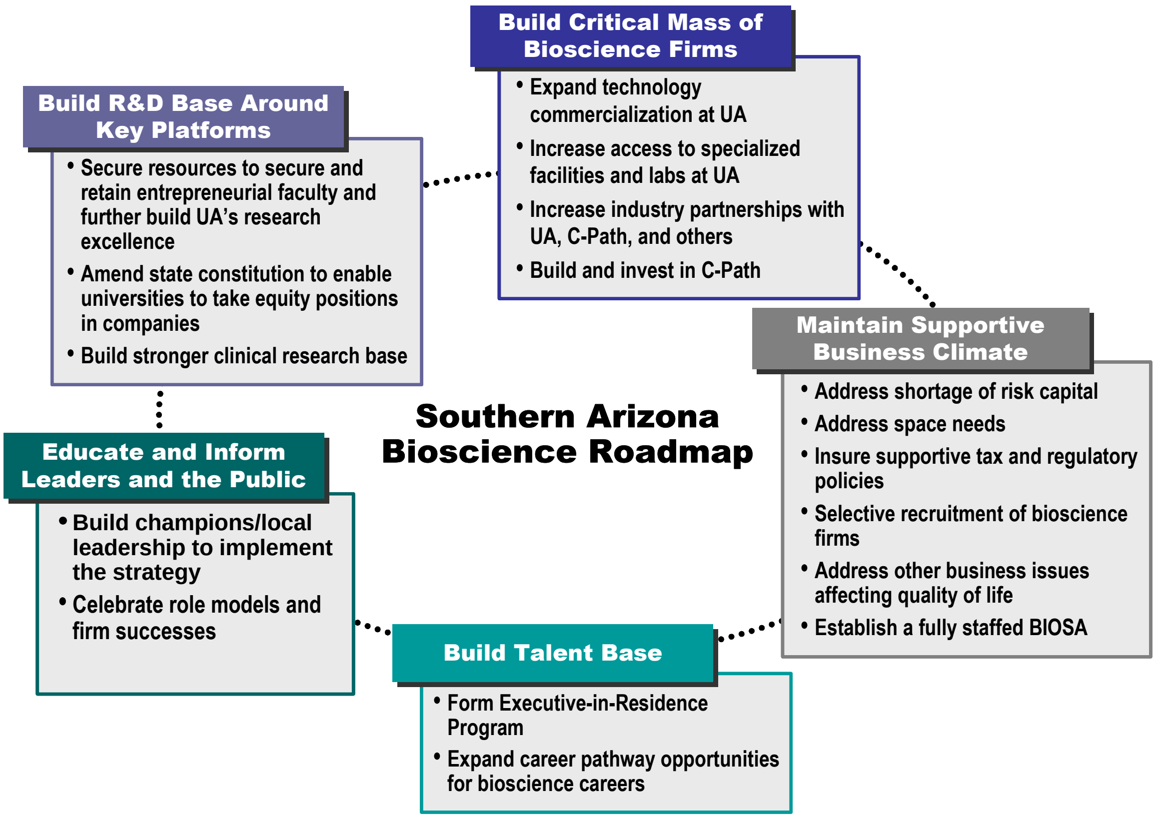
Strategy Three: Build a talent base that captures and retains Southern Arizona's human resources.

Strategy Four: Address and maintain a business climate supportive of the biosciences and their growth in Southern Arizona.

Strategy Five: Educate, inform, and spur to action opinion leaders and the general public on Southern Arizona's future in the biosciences.

These five strategies and the 17 actions proposed to achieve them are outlined in Figure ES-4. Each action is described in the full report. It is anticipated that 90 percent of these actions would be implemented over a 5-year time period. Specific metrics to monitor implementation of the Southern Arizona Bioscience Roadmap are contained in the full report.

Figure ES-4: Overview of Strategies and Actions



IMPLEMENTATION PLAN

The actions described in this Roadmap, while requiring some public catalytic action in the initial stages, rely, for the most part, on the private and philanthropic sectors, federal funding sources, and others to achieve significant progress and impact. In many cases, the effort is focused on ensuring that the private sector market gaps are addressed and filled over the long-term by private actions and private investments, such as addressing the need for risk capital, developing a bioscience research park, and increasing technical networking among firms and universities.

Immediate Work Plan Priorities

Immediate work plan priorities are those steps the private and public sectors in Southern Arizona should undertake in the first 12 months of implementation. Several critical priorities need to be implemented right away, while others will need to be planned and resources secured before they can move forward.

The following actions should be undertaken in the first year of Roadmap implementation:

- Identify champions and assign responsibility for Southern Arizona Bioscience Roadmap implementation
- Work with Science Foundation Arizona and state to secure their support in implementation of this Roadmap including funding for the following:

    - Research excellence—universities and technology anchors
    - Technology commercialization
    - Executives in residence
    - R&D pilot voucher program
- Complete work under NIH Clinical and Translational Science Award (CTSA) planning grant to seek full funding to further build capacity regionally and statewide
- Develop communications and education plan for the biosciences in Southern Arizona including role model success stories
- Move forward with bioscience park and incubator/accelerator space
- Monitor and assess C-Path progress and needs
- Complete planning for Biosciences Academy
- Assist in establishment of statewide BioSeed Fund
- Determine time frame for state constitutional amendment with Bioscience Steering Committee

Organization and Structure

This Regional Roadmap proposes a set of strategies and actions that involve many private and public sector organizations. There are four primary components to the issue of organization and structure for the Southern Arizona Bioscience Roadmap to move forward in implementation:

- Strengthen and expand the role of BIOSA by securing resources for full-time staff.
- Place responsibility for undertaking the interrelated issues of technology commercialization and business planning support services in one entity, whether it be at UA or with BIOSA.
- Complete work under NIH Clinical and Translational Science Award (CTSA) planning grant to seek full funding to further build capacity regionally and statewide
- Continue the existing Steering Committee or use the Southern Arizona Leadership Council Board as the key organization responsible for monitoring progress in implementation.

Conclusion

Southern Arizona represents Arizona's bioscience entrepreneurship center. It has a strong track record of start-ups succeeding start-ups in a robust genealogical tree, UA has a strong track record of bioscience spin-offs from its research, and both the university and industry are making plans to build further research excellence in their core competencies and achieve a critical mass of bioscience firms in the region. This Roadmap charts a set of strategies and actions for implementation over the next 5 years, identifies priorities and a time frame, identifies the resources required, and proposes measures of success and an organizational design and structure to oversee monitoring and implementation of this Roadmap.

Introduction

> *Arizona is the leading southwestern state in selective bioscience sectors, built around world-class research, clinical excellence, and a growing base of cutting-edge enterprises and supporting firms and organizations.*
>
> *Platform for Progress: Arizona's Bioscience Roadmap*, 2002[4]

In 2002, the State of Arizona adopted the above vision for Arizona's future. The state's public and private sectors joined together and committed to making the investments necessary to become a leading center for the biosciences. The *Arizona Bioscience Roadmap* called for building the state's infrastructure around selected technology platforms, growing a critical mass of bioscience firms, and offering a business climate and environment to support bioscience enterprises.

Much has been accomplished in building such an environment in Arizona since 2002. Arizona's public and private sectors have invested to build the state's bioscience infrastructure. The State of Arizona allocated $440 million for new bioscience research buildings and equipment. At least $35 million have been invested annually in biomedical research through the Arizona Biomedical Research Commission (ABRC) and funding made available through Proposition 301. Just this past year, the Greater Phoenix Leadership, Southern Arizona Leadership Council (SALC) and Flagstaff 40 created Science Foundation Arizona, a nonprofit organization that will award funds for bioscience research projects. The Foundation, whose mission is to spur development of the biosciences in Arizona, has received commitments of funds from the Stardust Foundation for its operating costs and $50 million from the Virginia G. Piper Charitable Trust to recruit additional research stars to the state. In addition, the Arizona Legislature appropriated $35 million to create a 21st Century Fund to spur medical, scientific, and engineering research that will be used to provide Science Foundation Arizona's funding support in its first year of operation.

Two key technology anchors, the Translational Genomics Research Center (TGen) and the Critical Path Institute (C-Path), have become fully operational and are attracting staff and dollars. TGen's six-story, $46 million building is the cornerstone of the Phoenix Biomedical Center, a bioscience and medical research campus under development in downtown Phoenix. C-Path, which was formed by the U.S. Food and Drug Administration (FDA), the University of Arizona (UA), and SRI International, is an independent, publicly funded, nonprofit organization located in Tucson that is dedicated to speeding up the process of bringing new drugs and therapies to the market. C-Path fosters research and educational programs to enable the pharmaceutical industry to safely accelerate the development of new medications.

Efforts also have been initiated to spur the creation and growth of new bioscience companies—the core base of which is found in Southern Arizona—by creating initiatives aimed at commercializing technology developed at Arizona's universities and research institutions and providing support to start-up and emerging bioscience companies. The Legislature created the Small Business Capital Investment Tax Incentive Program, also known as the Angel Investment Program, to expand the pool of capital available to bioscience and other qualified small businesses. Individuals who invest in qualified bioscience

[4] *Platform for Progress: Arizona's Bioscience Roadmap*. Prepared for the Flinn Foundation by Battelle Technology Partnership Practice. December 2002.

companies may receive a tax credit of up to 35 percent of the investment over a 3-year period. Such initiatives will result in the creation of new bioscience firms and the growth of emerging bioscience companies.

Significant progress has been made in building around the near-term bioscience platforms identified in the Roadmap, which include bioengineering, cancer therapeutics, and neurosciences, the base and strength of which resides at UA. Strategies for further developing these platforms have been adopted and are being implemented. Progress has also been made in addressing the need to develop cross-cutting areas, such as bioimaging, tissue, and translational research. Work is now beginning to address the mid-term platforms that include agricultural biotechnology, asthma, infectious diseases, and diabetes.

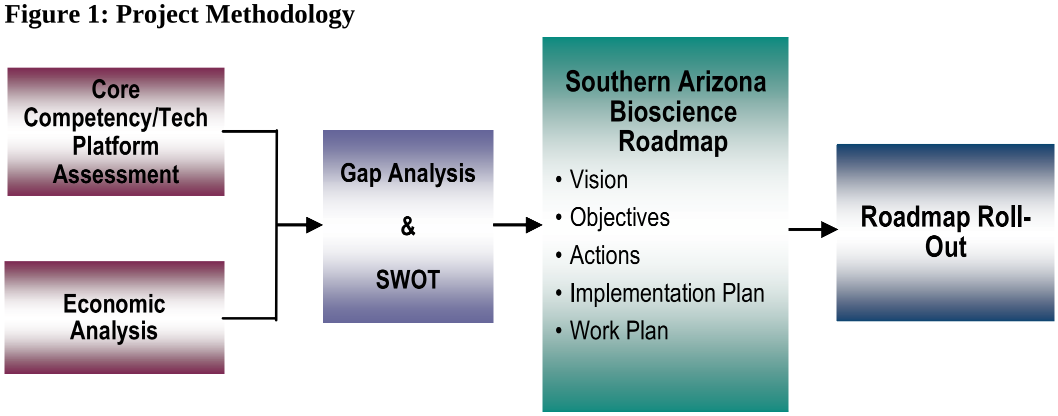
To continue this progress, the Flinn Foundation in 2006 engaged Battelle's Technology Partnership Practice (TPP) to comprehensively update the state's bioscience core competencies and technology platforms and to assist in preparing regional bioscience competitiveness roadmaps for both Northern and Southern Arizona. The regional roadmaps will complement the statewide Bioscience Roadmap, but will focus on the specific challenges and opportunities that exist at the regional level. The regional roadmaps will lay out a bioscience vision for Northern and Southern Arizona and identify the tactics, strategies, and actions required to achieve that vision.

The SALC took the lead in developing a bioscience roadmap for Southern Arizona and assembled the Southern Arizona Bioscience Steering Committee to oversee development of the plan. (Appendix A contains a list of the members of the project steering committee.) The Battelle team assisted the Steering Committee in developing this Roadmap.

Methodology

This Roadmap was developed with guidance and input from the region's research institutions, bioscience companies, and other public and private leaders. The Battelle project team collected and analyzed data on Southern Arizona's bioscience industry and research bases and interviewed academic, research, business, and civic leaders to develop an understanding of the region's existing bioscience research strengths and capabilities and to gather input on the types of investments needed to enable Southern Arizona to become a well-recognized regional bioscience center. Figure 1 displays the project methodology.

Figure 1: Project Methodology



This report

- Examines Southern Arizona's existing bioscience industry base.
- Proposes bioscience technology platforms that hold the greatest potential for development of the region's bioscience economy.
- Identifies gaps in private and public investments, policies, programs, and activities that need to be addressed if the region is to accelerate the growth of its bioscience economy.
- Sets forth a vision for the region's bioscience future.
- Presents a set of strategies and actions for achieving that vision.
- Outlines an implementation plan for moving forward.

Southern Arizona's Bioscience Industry Base

A critical component of any strategic regional plan is an economic assessment that examines the current state of the industry and investigates strengths and emerging opportunities for economic growth. Battelle examined employment and establishment data to assess the size and composition of Southern Arizona's bioscience sector and to identify emerging and existing subsector strengths that provide unique opportunities to grow the bioscience industry base in this region of the state.

THE BIOSCIENCE SECTOR

The biosciences represent a knowledge-based industry cluster driven by innovation in the life sciences. The industry combines cutting-edge laboratory research with the latest technologies to develop a range of products that boost productivity, advance health care, reduce environmental impacts, and potentially save lives.

Bioscience activity spans multiple markets and includes manufacturing, services, and research sectors. The sectors engaged in bioscience research and commercialization include **producers of agriculture-based goods** from feedstocks to fertilizers and bio-fuels such as ethanol; **pharmaceutical manufacturers that develop medicines and diagnostics; manufacturers of medical devices** ranging from magnetic resonance and other imaging equipment to surgical and laboratory appliances; the critical **research, testing**, **and medical laboratories sector** engaged in life sciences research and development (R&D); and the contributions of research hospitals and other research-driven institutions. Though each bioscience subsector has its own supply chains, research drivers, and other unique characteristics, nations and regions are building viable economic bases in the biosciences by promoting partnerships and shared resources with existing university, hospital, and industry anchors within and across these industry segments.

Key Findings

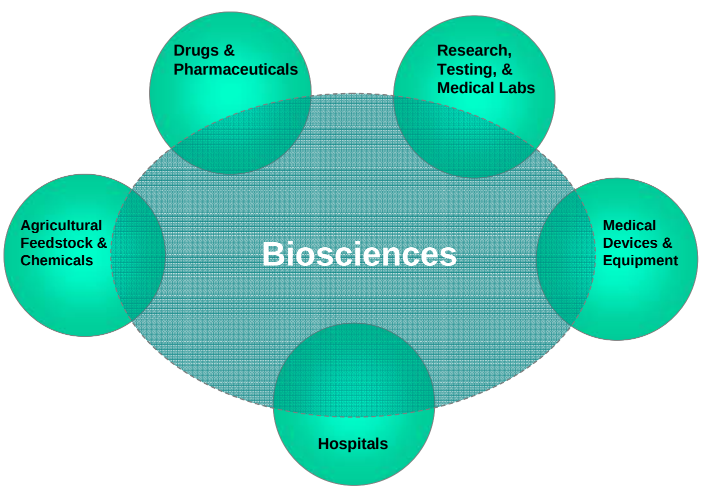
- Southern Arizona's bioscience sector is young, but has experienced rapid growth in total and across key subsectors.
- The largest bioscience subsector, hospitals, has a strong and growing regional presence.
- Employment growth and concentration in the research, testing, and medical laboratories subsector in Southern Arizona are greater than those for both Arizona and the national bioscience sector as a whole. Southern Arizona has a specialized life sciences R&D sector at the detailed industry level.
- The medical device and equipment subsector has established a presence in Southern Arizona and is characterized by "homegrown" firms that have a UA connection.
- Southern Arizona accounts for a large, disproportionate share of Arizona's overall bioscience sector and among several key subsectors. The region has an influential role in driving state bioscience trends.

The changing and diverse nature of the biosciences makes it difficult to define. The federal statistical system does not identify one complete bioscience industry classification. To encompass the range of bioscience activity in the United States, many detailed industries must be combined. Battelle has assisted many states and local areas throughout the United States in identifying and developing their bioscience industry bases. After years of research and field work, Battelle has identified five major subsectors that engage in key bioscience activity. The five major subsectors, shown in Figure 2, include the following:

- **Agricultural Feedstock and Chemicals**. This subsector applies life science knowledge and biotechnologies to the processing of agricultural goods and production of organic and agricultural chemicals. Product examples include ethanol, fertilizers, pesticides, sustainable lubricants and oils, and food and feed additives.
- **Drugs and Pharmaceuticals**. The subsector produces commercially available medicinal and diagnostic substances. Firms are generally large and multinational and are heavily engaged in R&D activities to bring drugs to market. Product examples include vaccines; oncology, neurology, and cardiology treatments; tissue and cell culture media; herbal supplements; and diagnostic substances.
- **Hospitals**.5 The subsector covers a wide range of health care services in addition to significant life science research. The sector includes general medical and surgical, psychiatric and substance abuse, and other specialty hospitals. Research hospitals, academic health centers, and other research-driven medical institutions are major contributors to life science R&D.
- **Medical Devices and Equipment**. Firms in this subsector produce biomedical instruments and other health care products and supplies for diagnostics, surgery, patient care, and laboratories. Product examples include bioimaging equipment, orthopedic and prosthetic implants and devices, dental instruments and orthodontics, laser eye surgery equipment, defibrillators (automated external defibrillators), and stents and other implantable devices.
- **Research, Testing, and Medical Laboratories**. This subsector includes a range of activities, from highly research-oriented companies developing and commercializing new drug discovery/delivery systems, to more service-oriented medical or other testing firms. Product examples include functional genomics and drug discovery techniques, diagnostic testing, preclinical drug therapeutics, protein receptors, and research models and laboratory support services.

The North American Industry Classification System (NAICS) is the official federal government system for classifying establishments and their activities into the appropriate sectors. The NAICS is based on the production processes of firms and categorizes them in groups with other establishments engaged in the same or similar activities. NAICS industries at the most detailed (six-digit) level were selected for this analysis and together make up the major sectors and subsectors. Using this system, 30 industries at the six-digit level of detail were chosen. These detailed industries were aggregated to five major subsectors of the bioscience industry. A full list of bioscience NAICS codes is shown in Table 1.

Figure 2: Bioscience Subsectors



[5] The inclusion of hospitals as a major bioscience subsector in the data analysis in this report differs from what Battelle used in its 2006 report for the Biotechnology Industry Organization (BIO), *Growing the Nation's Bioscience Sector: State Bioscience Initiatives 2006*. For this reason, total bioscience industry estimates will differ from those presented in the BIO report because employment in three detailed hospital codes from NAICS are included here. This analysis will, however, distinguish between these total bioscience data and the "nonhospital" bioscience totals that use the same four-subsector data from the BIO report.

Table 1: Bioscience Subsector Industries and NAICS Codes

NAICS Code	NAICS Description
Agricultural Feedstock & Chemicals	
311221	Wet corn milling
311222	Soybean processing
311223	Other oilseed processing
325193	Ethyl alcohol manufacturing
325199	All other basic organic chemical manufacturing
325221	Cellulosic organic fiber manufacturing
325311	Nitrogenous fertilizer manufacturing
325312	Phosphatic fertilizer manufacturing
325314	Fertilizer (mixing only) manufacturing
325320	Pesticide and other agricultural chemical manufacturing
Drugs & Pharmaceuticals	
325411	Medicinal and botanical manufacturing
325412	Pharmaceutical preparation manufacturing
325413	In-vitro diagnostic substance manufacturing
325414	Other biological product manufacturing
Hospitals	
622110	General medical and surgical hospitals
622210	Psychiatric and substance abuse hospitals
622310	Specialty hospitals
Medical Devices & Equipment	
334510	Electromedical apparatus manufacturing
334516	Analytical laboratory instrument manufacturing
334517	Irradiation apparatus manufacturing
339111	Laboratory apparatus and furniture manufacturing
339112	Surgical and medical instrument manufacturing
339113	Surgical appliance and supplies manufacturing
339114	Dental equipment and supplies manufacturing
339115	Ophthalmic goods manufacturing
339116	Dental laboratories
Research, Testing, & Medical Laboratories	
541380**	Testing laboratories
541710**	Physical, engineering, and biological research
621511	Medical laboratories
621512	Diagnostic imaging centers

**Includes only the portion of these industries engaged in relevant biological or other life science activities.

Two of the six-digit NAICS industries in Table 1—testing laboratories (NAICS 541380) and physical, engineering, and biological research (NAICS 541710)—were adjusted in this analysis to include only the share of these industries directly engaged in biological or other life science activities. To isolate these relevant life science components, Battelle used information and data from the U.S. Census Bureau's Economic Census.

Relevant bioscience activity in the hospitals subsector cannot be isolated. Ideally, one would segregate research hospitals, academic health centers, and other research-driven institutions to identify only the life science R&D that occurred in those settings. Unfortunately, there are no reliable ways in which to isolate these components from the three existing detailed hospital NAICS industries. The overall hospitals sector is included here because it is important and relevant, but this data issue and data limitations must be acknowledged and recognized.

Given the dynamic nature of the biosciences, one must also acknowledge the possibility that certain economic activities are not captured in this definition according to NAICS codes. Aggregating production activities on a broad scale will inevitably result in some data gaps; however, characterizing this industry according to the most detailed NAICS data available is the best approach to analyze the vast majority of key bioscience economic activity in Southern Arizona and the United States. Finally, the database used, which relies on employers' self-classifications for purposes of each state's unemployment compensation program, is dependent on both employer and state quality control measures; at times, employers may inappropriately classify themselves.

Data and Methodology

This economic analysis primarily examines data and corresponding trends in the Tucson Metropolitan Statistical Area (MSA)[6] and the United States as a whole in the biosciences from 2001 to 2004. The Tucson MSA includes only Pima County. For most of the employment analysis, Battelle has selected the Bureau of Labor Statistics' (BLS) Quarterly Census of Employment and Wages (QCEW) data set. The QCEW data (also known as the ES-202 program data) are the most current, detailed state-level industry employment, establishment, and wage figures available.[7] Battelle receives an "enhanced" version of these state and county data from a private vendor, the Minnesota IMPLAN Group, Inc.

The QCEW program is a cooperative program involving BLS and the State Employment Security Agencies. The QCEW program produces a comprehensive tabulation of employment and wage information for workers covered by state unemployment insurance (UI) laws and Federal workers covered by the Unemployment Compensation for Federal Employees Program. Publicly available files include data on the number of establishments, monthly employment, and quarterly wages, by NAICS industry, by county, by ownership sector, for the entire United States. These data are aggregated to annual levels, to higher industry levels (NAICS industry groups, sectors, and supersectors), and to higher geographic levels (national, state, and MSA).

[6] The U.S. Census Bureau defines an MSA as a core area containing a substantial population nucleus, together with adjacent communities having a high degree of social and economic integration with that core. Metropolitan and micropolitan statistical areas comprise one or more entire counties.

[7] In general, QCEW monthly *employment* data represent the number of covered workers who worked during, or received pay for, the pay period that included the 12th day of the month. Virtually all workers are reported in the state in which their jobs are located. Covered private-industry employment includes most corporate officials, executives, supervisory personnel, professionals, clerical workers, wage earners, piece workers, and part-time workers. It excludes proprietors, the unincorporated self-employed, unpaid family members, and certain farm and domestic workers. An *establishment* is an economic unit such as a farm, mine, factory, or store that produces goods or provides services. It is typically at a single physical location and engaged in one, or predominantly one, type of economic activity for which a single industrial classification may be applied. *Total wages*: Covered employers in most states report total compensation paid during the calendar quarter, regardless of when the services were performed. A few state laws, however, specify that wages be reported for or be based on the period during which services are performed, rather than for the period during which compensation is paid. Under most state laws or regulations, wages include bonuses, stock options, severance pay, the cash value of meals and lodging, tips and other gratuities, and—in some states—employer contributions to certain deferred compensation plans such as 401(k) plans. Major exclusions from UI coverage, and thus from the QCEW data, include self-employed workers (both farmers and nonagriculture), some wage and salary agricultural workers, unpaid family workers, railroad workers, and some state and local government workers.

Since 2001, the QCEW has been producing and publishing data according to the NAICS. Federal statistical agencies have a mandate to publish industry data according to this improved classification system. Compared with the prior classification system (the 1987 Standard Industrial Classification [SIC] system), NAICS better incorporates new and emerging industries.

Employment, establishment, and wage estimates produced by the QCEW program for 2001 to present are not comparable with SIC-based industry estimates from prior years. This limits the ability to construct a longer time series for data analysis; however, 4 years of NAICS-based data are available for analysis.

The following economic analysis examines the bioscience sector in Southern Arizona and the United States in 2004. It highlights the overall economic status of the sector and key trends over a 4-year period (2001 to 2004) and makes comparisons with the state and national bioscience sectors. The analysis identifies key existing subsector strengths, as well as emerging industries within the Southern Arizona bioscience industry segments.

Southern Arizona's Bioscience Industry[8]

Southern Arizona's bioscience sector is growing rapidly, considerably outpacing growth of bioscience employment nationally. The biosciences in Southern Arizona employed 14,644 people across 128 business establishments in 2004 (Table 2). Since 2001, the industry has experienced significant job growth, increasing by nearly 1,000 jobs or 7.1 percent. Southern Arizona's bioscience employment growth during the early 2000s was about 1.5 times as fast as that for the nation (up 4.8 percent).

The bioscience industry in both Southern Arizona and the United States outperformed their counterparts in the private sector. Southern Arizona private sector employment growth reached 3.3 percent, while the overall U.S. private sector *decreased* by 0.7 percent. Private sector job gains for Southern Arizona signal a regional economy poised for growth from 2003 to 2004, when Southern Arizona boosted employment by 4 percent.

The decline in national private sector employment from 2001 to 2004 is not surprising, given the overall economic weakness and sluggish labor market following the relatively short recession in 2001.[9] It is important to keep in mind the business cycle context of the time period being discussed. Job gains in any industry during the early 2000s are especially noteworthy given the prevailing labor market conditions at that time.

From 2001 to 2004, Southern Arizona increased its number of bioscience establishments by 13 percent. This outpaced firm growth at the national level and was nearly three times the pace of the private sector. A steady increase in the number of business establishments signifies new business investments and entrepreneurial activity.

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[8] Employment data are for the private sector only and therefore do not include the large number of bioscience researchers employed by UA.

[9] The National Bureau of Economic Research (NBER) Business Cycle Dating Committee is the official arbiter of U.S. Business Cycles. The Committee determined that a peak in the business cycle occurred in March 2001, marking the end of an expansion and the beginning of a recession. The peak ended a record-long expansion (10 years). The business cycle trough occurred in November 2001, ending a recession of relatively short duration. For more information, visit http://www.nber.org/cycles.html/.

Table 2: Southern Arizona and National Bioscience Industry Comparison, 2001–2004

Metric	Southern Arizona		United States	
	Biosciences	Total Private Sector	Biosciences	Total Private Sector
Establishments				
2001	113	16,735	43,455	7,733,520
2004	128	17,504	47,114	8,105,643
2001-04 % change	13.3%	4.6%	8.4%	4.8%
Employment				
2001	13,669	266,608	5,200,957	109,321,800
2004	14,644	275,286	5,449,340	108,505,300
2001-04 % change	7.1%	3.3%	4.8%	-0.7%
Average Annual Wages				
2001	$33,036	$29,784	$41,120	$36,159
2004	$40,004	$32,777	$47,582	$39,127
2001-04 % change	21.1%	10.0%	15.7%	8.2%
Location Quotient				
2001	1.08	NA	1.00	NA
2004	1.06	NA	1.00	NA
Share of Private Sector Employment (Percent)				
2001	5.1%	100%	4.8%	100%
2004	5.3%	100%	5.0%	100%

Source: Battelle calculations based on BLS, QCEW/ES-202 program data and Minnesota IMPLAN Group, Inc.

The bioscience sector presence in Southern Arizona is significant; at 5.3 percent of total private sector employment, the industry has a slightly greater employment concentration in Southern Arizona than at the national level (5.0 percent). Location quotients (LQs) quantify this relative degree of employment concentration.[10] An LQ of 1.0 indicates a similar degree of concentration as for the nation. When the region has significantly above-average employment—an LQ greater than 1.20—the area is said to possess a specialization in that industry. Figure 3 shows the formula for calculating an LQ.

[10] Location quotients are a standard measure of the concentration of a particular industry in a region relative to the nation (reference area). The LQ is the share of total regional employment in the particular industry divided by the share of total industry employment in the nation (reference area). An LQ greater than 1.0 for a particular industry indicates that the region is relatively concentrated, whereas an LQ less than 1.0 signifies a relative underrepresentation. An LQ greater than 1.20 denotes employment concentration significantly above the national average. Throughout this report, LQs are used to report regional industry concentrations relative to the U.S. as a whole. The minimum concentration threshold for declaring a regional specialization is a matter of judgment and varies somewhat in the relevant literature. In this analysis, regional specializations are defined by LQs of 1.20 or greater.

Figure 3: Calculating a Location Quotient (LQ)

$$LQ_{it} = (E_i / E_t) / (US_i / US_t)$$

Where: E_i = **Industry *i* regional employment**
E_t = **Total regional employment**
US_i = **Industry *i* national employment**
US_t = **Total national employment**

The LQ for the Southern Arizona bioscience industry stands at 1.06 in 2004—employment in Southern Arizona is 6 percent more concentrated than at the national level. While it is not considered to be regionally specialized overall, the biosciences have a clear presence in Southern Arizona. The LQ dipped slightly from 1.08 in 2001. A change in the LQ can result from changes in total employment and/or industry employment at either the regional and/or national level. Though bioscience employment increased at both the regional and national levels, the bioscience share of U.S. employment (the denominator) increased slightly more over the period than did the bioscience share of Southern Arizona employment (the numerator).

The biosciences pay well, offering a substantial wage premium that illustrates the significant demand for well-educated, highly skilled labor. The biosciences employ a high concentration of individuals with technical skills, including engineers, scientists, and technicians. The average annual salary for Southern Arizona bioscience workers topped $40,000 in 2004, more than $7,000 (or 22 percent) more per year than for their counterparts in the overall private sector ($32,777).[11]

While Southern Arizona wages are generally lower than the national average, recent wage gains in Southern Arizona have outpaced those for the nation. Southern Arizona bioscience workers have seen average salaries increase by 21 percent, compared with almost 16 percent at the national level.

Southern Arizona's share of total 2004 bioscience employment in Arizona is 19.7 percent, significantly greater than its 13.9 percent share of total private sector employment. Southern Arizona, therefore, has a disproportionate influence on overall state trends and helps to drive the state's bioscience sector.

Nonhospital Biosciences

Given that hospitals comprise the vast majority of total bioscience employment in both Southern Arizona and the United States—87 percent and 78 percent of total 2004 bioscience employment, respectively—it is useful to examine the nonhospital bioscience subtotals before moving on to the detailed subsector analysis.

Southern Arizona's nonhospital bioscience sector is modest in size, but rapidly growing. The nonhospital sector employs nearly 2,000 individuals across 112 business establishments (Table 3). These workers are almost all within two of the four major nonhospital subsectors—medical devices and equipment and research, testing, and medical laboratories. While the nonhospital biosciences overall have a modest LQ—0.65 in 2004—the sector is growing at a rapid pace. ***Since 2001, the Southern Arizona nonhospital biosciences have seen employment rise by 21.9 percent, compared with only 0.9 percent nationally***. This strong employment growth boosted the regional LQ as the concentration of bioscience workers in Southern Arizona moved higher relative to the nation.

[11] Average annual wages per employee for any given industry are computed by dividing total annual wages by annual average employment. Annual pay data only approximate annual earnings because an individual may not be employed by the same employer all year or may work for more than one employer at a time. Average weekly or annual pay is affected by the ratio of full-time to part-time workers, as well as by the numbers of individuals in high-paying and low-paying occupations. When comparing average pay levels among states and industries, data users should take these factors into consideration.

The Southern Arizona nonhospital bioscience sector represents 16.5 percent of the total nonhospital biosciences in Arizona. Like the overall bioscience sector, it also exceeds the 13.9 percent share of private sector employment and thus has an influential role in the overall state sector. This regional role holds especially true for the research, testing, and medical laboratories sector (18.0 percent of the state sector), as well as for the medical devices and equipment sector (19.1 percent of the state sector).

Average wages for nonhospital bioscience workers tend to be significantly greater than for the overall biosciences. In 2004, nonhospital bioscience workers in Southern Arizona earned $47,476, on average, compared with $32,777 for the average private sector worker (Table 3). Nationwide, nonhospital bioscience workers earn a substantial $66,636 average annual wage. While a portion of the U.S.-Southern Arizona bioscience wage gap is explained by generally higher wages for the United States, much of the difference is due to the differing composition of subsectors. Southern Arizona has almost no employment in the highest-paying subsector—drugs and pharmaceuticals.

Table 3: Southern Arizona and National Nonhospital Bioscience Industry Comparison, 2001–2004

Metric	Southern Arizona		United States	
	Nonhospital Biosciences	Total Private Sector	Nonhospital Biosciences	Total Private Sector
Establishments				
2001	97	16,735	36,346	7,733,520
2004	112	17,504	39,595	8,105,643
2001-04 % change	16.4%	4.6%	8.9%	4.8%
Employment				
2001	1,614	266,608	1,191,619	109,321,800
2004	1,968	275,286	1,201,895	108,505,300
2001-04 % change	21.9%	3.3%	0.9%	-0.7%
Average Annual Wages				
2001	$43,462	$29,784	$58,574	$36,159
2004	$47,476	$32,777	$66,636	$39,127
2001-04 % change	9.2%	10.0%	13.8%	8.2%
Location Quotient				
2001	0.56	NA	1.00	NA
2004	0.65	NA	1.00	NA
Share of Private Sector Employment (Percent)				
2001	0.6%	100%	1.1%	100%
2004	0.7%	100%	1.1%	100%

Source: Battelle calculations based on BLS, QCEW/ES-202 program data and Minnesota IMPLAN Group, Inc.

To understand the overall trends in the Southern Arizona bioscience industry, it is critical to understand its component subsectors. The following section focuses on these major subsectors and underlying trends that drive the biosciences in the region.

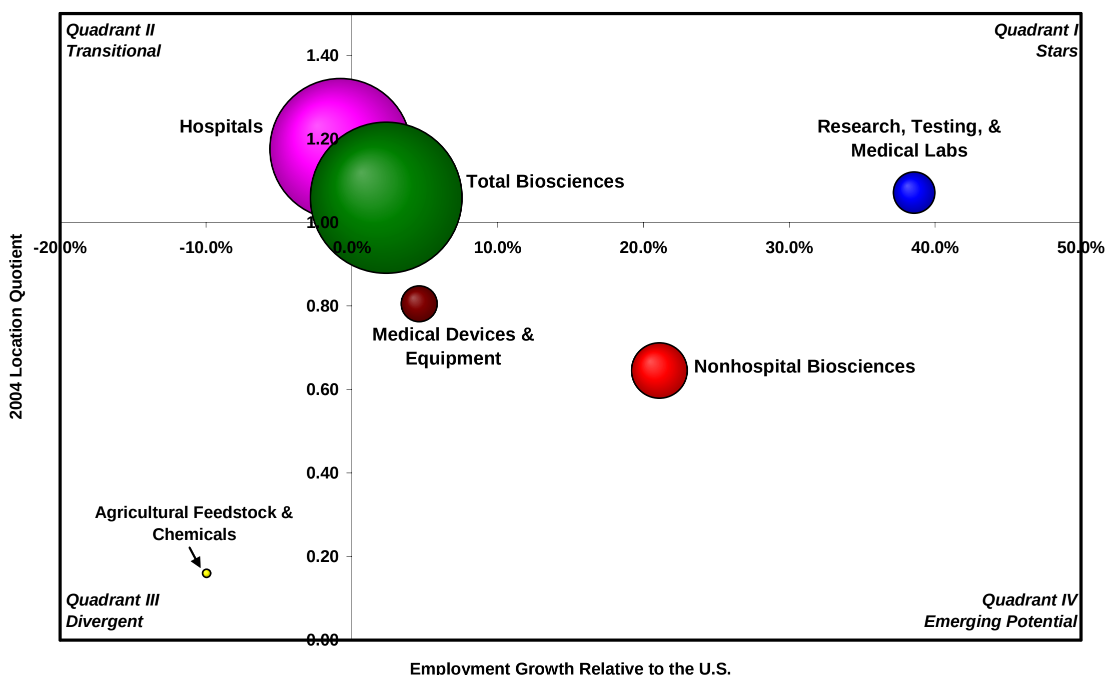
SOUTHERN ARIZONA'S BIOSCIENCE SUBSECTORS

The diverse and dynamic nature of the biosciences calls for a closer inspection of its major components. Overall magnitudes and trends can be explained only by examining the subsectors that compose the overall sector. Component industries and their activities and characteristics often differ greatly from one another. While the overall sector is generally engaged in value-added activities involving living organisms, the approach to research and industrial/commercial applications among the subsectors varies.

A detailed subsector analysis identifies those characteristics making each sector unique and define its progress. Taken in the context of the regional economy with national comparisons, each subsector's strengths and potential emerge. Each opportunity for development and growth identified among these component industries can benefit the entire bioscience sector and further the benefits derived from their convergence.

Figure 4 illustrates the degree of specialization, relative employment growth, and employment size of four of the five major bioscience subsectors (drugs and pharmaceuticals is not included because of a lack of employment), as well as the bioscience total and the nonhospital bioscience subtotal. The bubble chart plots 2004 LQs against the difference in industry employment growth between Southern Arizona and the United States from 2001 to 2004. The size of each bubble represents employment size.

Figure 4: Southern Arizona's Bioscience Subsectors, Degree of Specialization, Employment Growth, and Size, 2001–2004



Note: Size of bubble represents 2004 employment level.

Figure 4 reveals the strong relative employment growth of the Southern Arizona biosciences during 2001 to 2004. Compared with the United States, Southern Arizona subsector employment grew at a faster rate in research, testing, and medical laboratories and in medical devices and equipment. The hospitals subsector had a slightly lower job growth rate than did the United States, and job losses in the agricultural feedstock and chemicals subsector were worse than for the nation. It is important to note, however, that the percent decrease in the agricultural feedstock and chemicals sector appears dramatic because of its very small employment base (fewer than 50 regional jobs).

Quadrant locations within Figure 4 reveal certain key characteristics and trajectories for each subsector. The northeast quadrant, labeled “stars,” highlights industries with positive relative job growth and employment concentrations that exceed those for the nation. In Southern Arizona, the research, testing, and medical laboratories subsector and the overall bioscience industry cluster can be thought of as “stars.” Referring to an industry as a regional star might be misleading, however. While the industry is clearly heading in the right direction with strong growth and concentration of workers, the overall size might be modest, and work must continue to further establish the industry as a “specialized” one (LQ exceeding 1.20). The location of the overall bioscience sector in this northeast quadrant, though, is very positive for the region.

Subsectors that display “emerging potential” in the southeast quadrant of Figure 4 are critical to recognize as potential future stars of industry. Subsectors in this quadrant are demonstrating strong growth relative to the nation, but have a lower employment concentration than the national industry (LQ less than 1.00). By acknowledging the potential of up-and-coming bioscience industries, a region can continue to grow its bioscience base through targeted efforts based on quantitative evidence.

The research, testing, and medical laboratories subsector is the fastest growing and the largest among the nonhospital subsectors. The subsector employed 1,100 in the Southern Arizona in 2004 (Table 4). The region added more than 300 jobs during 2001 to 2004, a gain of 45.6 percent. These Southern Arizona jobs span 51 business establishments and yield an employee-per-establishment figure of 21, about average for the sector at the national level.

At the national level, the research, testing, and medical laboratories subsector also experienced strong employment growth, rising 7 percent since 2001 despite overall weak labor market conditions. Like Southern Arizona, employment in this subsector grew faster than in any of the other bioscience subsectors. In addition, national subsector establishments rose by 20 percent, far exceeding the firm growth in other subsectors. When an industry exhibits this robust growth in an overall weak economic climate, it is clear that the sector is a national strength and capital investments will continue.

Research, testing, and medical laboratories in Southern Arizona posted a 1.07 LQ in 2004, making it a concentrated industry subsector. Employment concentration in this critical bioscience subsector is 7 percent greater in Southern Arizona than for the entire United States. ***In Battelle’s 2006 national report for the Biotechnology Industry Organization (BIO), the Tucson metropolitan area ranked 28th among all large metropolitan areas (72 total) for its LQ in the research, testing, and medical laboratories subsector in 2004***.[12]

[12] *Growing the Nation’s Bioscience Sector: State Bioscience Initiatives 2006.* Prepared for BIO by Battelle Technology Partnership Practice and SSTI, April 2006. The full report can be accessed online at http://www.bio.org/local/battelle2006/.

Table 4: Southern Arizona and National Bioscience Subsectors, 2001–2004

SOUTHERN ARIZONA	Agricultural Feedstock & Chemicals	Drugs & Pharmaceuticals	Medical Devices & Equipment	Research, Testing, & Medical Labs	Hospitals
Establishments					
2001	3	-	49	45	16
2004	3	1	57	51	16
2001-04%change	-8.2%	-	17.2%	15.0%	0.0%
Employment					
2001	55	-	803	756	12,055
2004	45	8	815	1,100	12,676
2001-04%change	-18.3%	-	1.5%	45.6%	5.2%
Average Annual Wages					
2001	$32,904	$-	$35,503	$52,689	$31,640
2004	$37,040	$61,333	$33,532	$58,140	$38,845
2001-04%change	12.6%	NA	-5.6%	10.3%	22.8%
Location Quotient					
2001	0.19	-	0.80	0.82	1.23
2004	0.16	0.01	0.81	1.07	1.18
Share of Private Sector Employment (Percent)					
2001	0.0%	0.0%	0.3%	0.3%	4.5%
2004	0.0%	0.0%	0.3%	0.4%	4.6%
UNITED STATES	**Agricultural Feedstock & Chemicals**	**Drugs & Pharmaceuticals**	**Medical Devices & Equipment**	**Research, Testing, & Medical Labs**	**Hospitals**
Establishments					
2001	2,128	2,519	15,077	16,622	7,109
2004	2,082	2,499	15,057	19,957	7,519
2001-04%change	-2.2%	-0.8%	-0.1%	20.1%	5.8%
Employment					
2001	121,187	280,608	411,569	378,255	4,009,338
2004	111,103	287,181	398,886	404,725	4,247,445
2001-04%change	-8.3%	2.3%	-3.1%	7.0%	5.9%
Average Annual Wages					
2001	$58,011	$72,407	$48,707	$59,229	$35,933
2004	$64,518	$82,060	$57,365	$65,410	$42,190
2001-04%change	11.2%	13.3%	17.8%	10.4%	17.4%
Share of Private Sector Employment (Percent)					
2001	0.1%	0.3%	0.4%	0.3%	3.7%
2004	0.1%	0.3%	0.4%	0.4%	3.9%

Source: Battelle calculations based on BLS, QCEW/ES-202 program data and Minnesota IMPLAN Group, Inc.

Two of every three jobs in the Southern Arizona research, testing, and medical laboratories subsector are in the life science component of the R&D detailed industry (NAICS 541710). In addition to being the major component, this detailed industry is also the primary driver of job growth, itself growing by more than 60 percent from 2001 to 2004. This detailed industry covers a wide range of firms conducting research and experimental development in the life sciences—agriculture, environment, biology, botany, biotechnology, chemistry, health, medicine, and much more. Activities in this industry are at the heart of the biosciences. Investments in biological research yield new technologies and products and are the foundation for future economic growth.

The other major component of this Southern Arizona subsector is medical laboratories. About 27 percent of total subsector employment lies within this detailed industry. It too has grown since 2001; employment has risen by more than 40 percent. The medical laboratories industry includes firms engaged in medical analysis or diagnostic services, including body fluid analysis of patients.

Southern Arizona is successfully building a core economic and employment base in the research, testing, and medical laboratories subsector. Characterized by rapid employment growth and a strong relative concentration of jobs, the subsector has positioned itself in the industry "stars" category. The challenge for the region will be to continue to expand its base and attract top technical talent in the workforce.

Examples of Tucson's Research, Testing, and Medical Lab Firms

- **High Throughput Genomics, Inc. (HTG)** is a biological research and testing firm. HTG is engaged in functional genomics and developing drug discovery techniques. The company seeks to help researchers bring drugs to market in an efficient manner. HTG produces a variety of assays to measure deoxyribonucleic acid (DNA), gene expression, and proteins.
- **Sonora Quest Laboratories** has a 15,000-square-foot testing facility. It is affiliated with Quest Diagnostics and Banner Health and provides an extensive array of testing services for Southern Arizona. Sonora Quest conducts clinical testing including cholesterol, cytology, pap smears, microbiology, hematology, and general chemistry. The Tucson laboratory operates 24 hours a day, 7 days a week and employs a large staff.

Hospitals are by far the largest among the five major bioscience subsectors in Southern Arizona, with nearly 13,000 individuals employed in the industry. The hospitals subsector includes 16 regional establishments, unchanged from 2001. The subsector added about 600 jobs in Southern Arizona from 2001 to 2004, boosting employment by 5.2 percent. At the national level, hospital employment had a similar increase, up 5.9 percent.

Southern Arizona has a relatively high concentration of hospital employment compared with the overall U.S. hospitals sector. Its 2004 LQ was 1.18, 18 percent greater concentration than the U.S. average and close to the 20 percent threshold to be considered "specialized." While hospital employment did increase in the early 2000s, its LQ had a slight decrease from 1.23 (when it was considered to be a specialized industry). This decline in the LQ—from 1.23 to 1.18—results from a slightly larger increase in the national hospitals' share of total employment over the period (the denominator in the LQ equation).

The Southern Arizona hospitals subsector makes up 20.3 percent of total Arizona hospital employment. This share exceeds that for both the overall private sector (13.9 percent of state total), as well as the overall bioscience sector (19.7 percent). Southern Arizona's regional influence on the overall state medical sector derives from employing one in five state hospital workers.

Southern Arizona's niche in the hospitals subsector of the biosciences results, in large part, from the key research and other work at the University Medical Center (UMC). UMC has been ranked among the nation's best hospitals by *U.S. News & World Report* in numerous medical specializations. In the 2006 edition,[13] the hospital ranked among the top 50 U.S. hospitals in the following categories:

[13] "Best Hospitals 2006—University Medical Center, Tucson, Ariz." *U.S. News & World Report*, http://www.usnews.com/usnews/health/best-hospitals/directory/glance_6860516.htm.

- Heart and Heart Surgery (16th)
- Respiratory Disorders (20th)
- Cancer (22nd)
- Neurology and Neurosurgery (22nd)
- Urology (26th)
- Kidney Disease (39th)
- Orthopedics (41st)
- Digestive Disorders (45th).

UMC in Tucson is a national leader in bioscience research and derivative medical specialties. The hospital, part of the Arizona Health Sciences Center (AHSC), is affiliated with key programs of UA College of Medicine, including the Arizona Cancer Center, Arthritis Center, Steele Children's Research Center, and the UA Sarver Heart Center. These partnerships form a critical confluence of university research and practical medicine and have contributed to major medical breakthroughs.

Manufacturers of medical devices and equipment have a significant presence in Southern Arizona. Firms engaged in the production of medical devices, supplies, and instruments employ more than 800 in Southern Arizona, up slightly (1.5 percent) since 2001. Nationally, the subsector shed jobs during the early 2000s—employment declined by 3 percent and the number of U.S. establishments was essentially flat. Southern Arizona added to its medical device establishments, which totaled 57 in 2004.

Employment concentration in medical devices and equipment stands at about 80 percent of that for the United States (LQ is 0.81). While substantial, this key "emerging" bioscience manufacturing sector in Southern Arizona must continue to add new firm employment, as well as adding jobs to its existing base of companies to meet the national average concentration.

The presence of viable cutting-edge producers like Ventana Medical Systems in Oro Valley is exciting for this important regional bioscience subsector. Ventana is a relatively large, growing producer of diagnostic instruments and reagent systems that conducts all of its R&D and manufacturing in Southern Arizona. Its products focus on cancer diagnostics and tissue and biopsy analysis using automated slide technology. Ventana's business success has generated national attention; the firm is listed at number 35 on *Fortune Magazine's* 2006 Small Business 100 list.[14] The company is homegrown and developed from the strong biotechnology "lineage" from the UMC and has developed a global presence, with employees in Europe and Japan.

Medical device producers like Ventana rely on cooperation with research hospitals and other leading biomedical institutions. The presence of UA and UMC and their research strengths have led to many commercial successes in local firms with UA roots. This is a prime example of opportunities that emerge from the targeted clustering of existing regional resources and commercial opportunities.

Southern Arizona has little presence in the drugs and pharmaceuticals subsector. The nature of a strong research and testing subsector, however, is promising for future developments in the drug and pharmaceutical realm. In today's bioscience economy, up-and-coming drug and pharmaceutical firms often have spent years in the R&D phase. Firms classified in the research sector are investing funds and

[14] "The FSB 100." *Fortune Small Business*, http://money.cnn.com/magazines/fsb/fsb100/2006/full_list/.

time today to develop medicines and therapeutics for the future. Given the young nature of the biosciences in Southern Arizona and the limited maturity of the research and testing subsector, it is likely that some of these firms will realize research breakthroughs and soon *become* producers of drugs and pharmaceuticals.

In addition, it is important to be aware that employment data in this analysis are available only through 2004. Given recent activity among Southern Arizona firms around drug and pharmaceutical development, it is likely that some production could begin or has begun in the region during the last 2 years.

Nationally, this subsector tends to be highly concentrated with large, multinational firms located in a few states. Unlike other regions trying to attract drug and pharmaceutical producers, Southern Arizona has characteristics, such as a high concentration of biological R&D and a premier research university and hospitals, that may attract potential pharmaceutical operations to the region. In addition, local firms as well as those headquartered outside the region or state are proven innovators in Southern Arizona, with a significant base of patents related to therapeutics and pharmaceuticals. A major challenge in this industry is the ability to attract and retain a talented manufacturing workforce.

Nationally, the drugs and pharmaceuticals subsector is growing (employment is up 2.3 percent since 2001) and generally has the highest-paying jobs in the biosciences. With an aging population and high-value R&D investments globally, this industry has generated profits and good jobs among different regions.

The fifth major bioscience subsector, agricultural feedstock and chemicals, also has little presence in Southern Arizona. Southern Arizona has three establishments and fewer than 50 jobs in this biobased production sector. The agricultural feedstock and chemicals subsector is the smallest employer among the national bioscience subsectors, with just over 111,000 jobs. The sector shed 8 percent of national employment during the early 2000s.

Geography and climate play a role in the production (or lack thereof) of agricultural feedstock, and this is clearly the case with Southern Arizona. Regions not engaged in the production of agriculture are often engaged in this subsector through the production of biobased chemicals.

The following section of this Roadmap will analyze the annual wages of bioscience workers in Southern Arizona.

SUBSECTOR ANNUAL WAGE ANALYSIS

Analyzing wages across the major bioscience subsectors provides insight into the demand and relative supply of workers in Southern Arizona. In addition, it highlights those industries with the highest-paying jobs for the region to target in its development efforts. A higher-paying sector implies a greater degree of value added to a good produced or a service provided. In developing its bioscience economy, Southern Arizona can look to wage rates as a key indicator of the market's allocation of capital.

A snapshot of annual wages in 2004 shows the rather dramatic premium paid to bioscience workers versus their counterparts in the overall private sector (Table 5). ***In 2004, the average bioscience worker in Southern Arizona earned $40,004, which is $7,227 (or 22 percent) more than the $32,777 for the average worker in the private sector***. This wage premium holds true at the national level where the average bioscience worker earns $8,455 (or 22 percent) more than the average worker in the private sector—$47,582 versus $39,127.

Table 5: Average Annual Wages in Southern Arizona for the Biosciences and Other Major Industries, 2004

Major Southern Arizona Industry	2004 Average Wages
Computer & Peripheral Equipment manufacturing	$88,087
Aerospace manufacturing	$77,323
Drugs & Pharmaceuticals	**$61,333**
Research, Testing, & Medical Laboratories	**$58,140**
Manufacturing	$57,974
Semiconductor & Electronic Component manufacturing	$57,902
Professional, Scientific, & Technical Services	$49,337
Finance & Insurance	$49,098
Information	$47,830
Total Nonhospital Biosciences	**$47,476**
Total Biosciences	**$40,004**
Hospitals	**$38,845**
Agricultural Feedstock & Chemicals	**$37,040**
Health Care & Social Assistance	$36,153
Medical Devices & Equipment	**$33,532**
Total Private Sector	**$32,777**
Construction	$31,484
Real Estate & Rental & Leasing	$29,408

Source: Battelle calculations based on BLS, QCEW program data from IMPLAN.

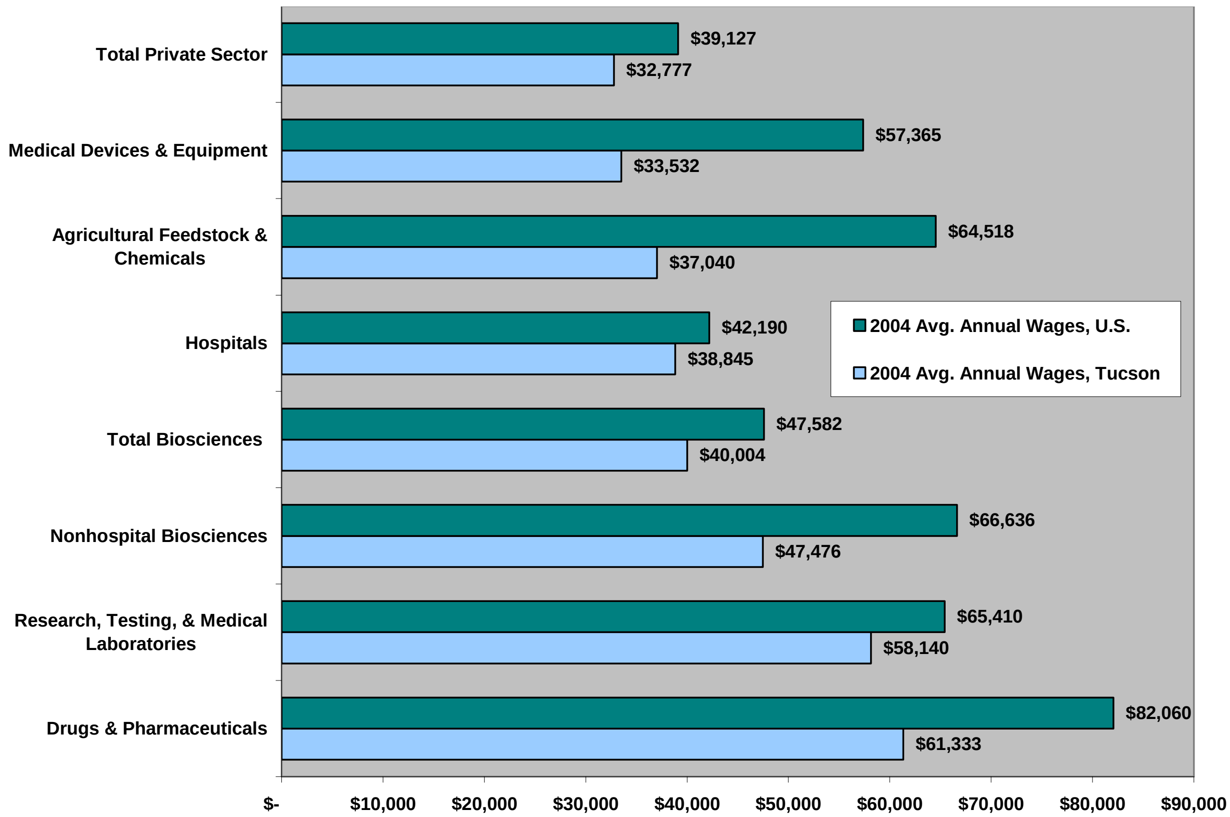
Average wages in the nonhospital bioscience sector tend to be higher than average hospital wages. In 2004, the average annual salary in the nonhospital sector was $47,476, nearly $15,000 more than the private sector average. At the national level, 2004 nonhospital bioscience wages averaged $66,636, which is $27,509 (or 70 percent) more than the average wage for the entire U.S. private sector.

A wage premium of varying magnitudes holds for each of the five major bioscience subsectors in Southern Arizona over the private sector. Workers in drugs and pharmaceuticals earn the highest average annual wage among the subsectors, $61,333. The overall lack of employment in this subsector, however, contributes in part to the generally lower average wages for Southern Arizona bioscience workers compared with their counterparts at the national level.

Southern Arizona's significant niche in the research, testing, and medical laboratories subsector is accompanied by high wages for its employees. The average for the sector in 2004 was $58,140, among the highest average wages paid among all major industries. This highlights the strong demand for these skilled workers. The subsector employs a high concentration of workers in technical occupations—scientists, engineers, and technicians who are well-educated, highly skilled, and commanding higher wages. At both the regional and national levels, wages in this subsector are rising fast, exceeding 10 percent growth during the early 2000s in both cases.

Figure 5 compares 2004 wages for the United States and Southern Arizona in the biosciences and major subsectors. As holds true for the overall private sector, all average Southern Arizona wages are below those of the national averages. No one element can explain this overall wage differential; but, explanatory variables would include the overall cost of living, relative skill differentials in the region versus the nation, differences in the occupational composition of these industries at the regional level, the level of education of local workers, differences in employee tenure, and other wage-determining factors.

Figure 5: U.S. and Southern Arizona Average Annual Wages in the Biosciences and Subsector Industries, 2004



Overall strong wage and employment growth in the two largest Southern Arizona bioscience industries—hospitals and research, testing, and medical laboratories—is a promising trend for the region. Demand for workers in these subsectors is clearly strong and growing.

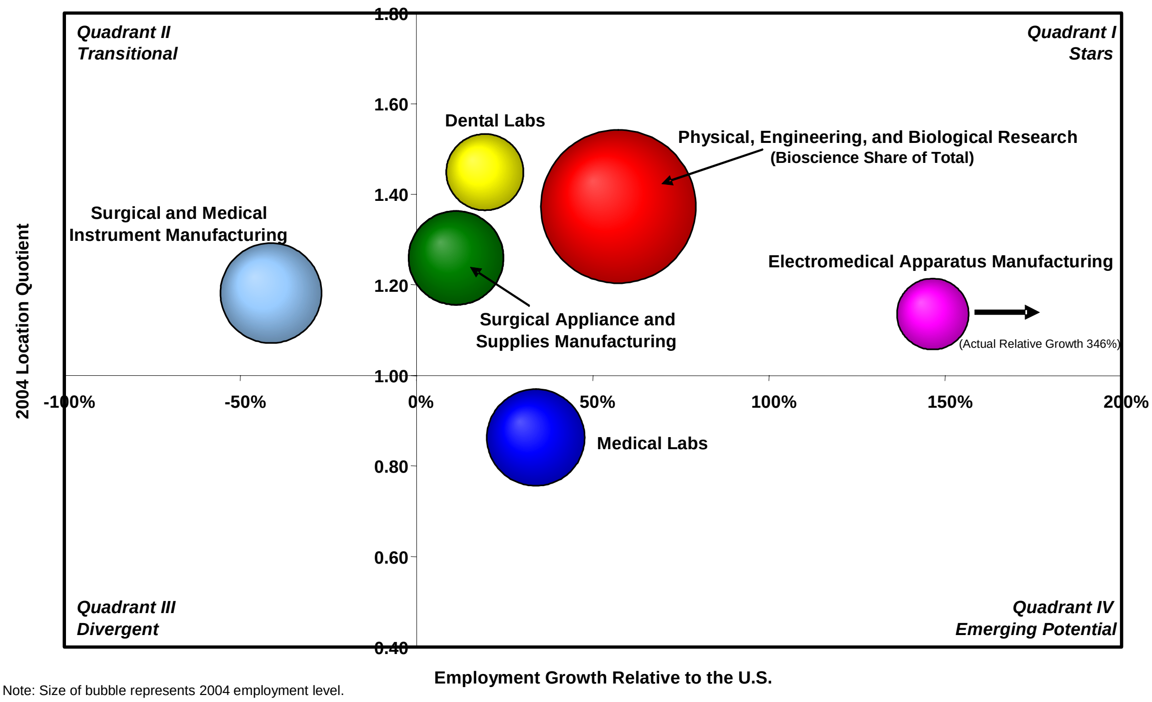
The following section will analyze detailed industries within the major subsectors that have demonstrated strength and/or emerging potential in the growing regional bioscience sector.

SOUTHERN ARIZONA'S DETAILED BIOSCIENCE INDUSTRY STRENGTHS

Because of the biosciences' diverse activities, a more detailed decomposition of the major subsectors is needed to identify those industries driving growth or beginning to emerge in relative importance. These detailed subsector strengths can provide more useful targets for Southern Arizona. Caution is required, however, when examining magnitudes and trends at this most detailed industry level. Minor changes within small industries or one establishment can be magnified and interpreted as a major shift. To help control for this to some degree, the following detailed industry analysis is limited to those with a Southern Arizona employment base of at least 150 in 2004.

Each major subsector in this analysis is made up of detailed six-digit NAICS industries. Figure 6 shows the relative performance of six of these industries in the nonhospital biosciences that employ at least 150 in Southern Arizona. Among the nonhospital industries, these six cover the vast majority of employment.

Figure 6: Employment Change Among Key Bioscience Industries in Southern Arizona Relative to the United States (2001–2004) and 2004 LQs



Note: Size of bubble represents 2004 employment level.

The largest among the detailed industries is the major component of the research, testing, and medical labs subsector—the biosciences component of NAICS 541710, physical, engineering, and biological research. This life science research sector has exhibited strong employment growth and has an LQ of 1.37, making it regionally specialized. This specialization extends to a critical role in driving the detailed industry at the state level. ***Southern Arizona's bioscience R&D industry accounts for 58 percent of total Arizona employment in that sector***. Table 6 highlights this and two other detailed industries that are regionally specialized and growing.

Dental laboratories is a specialized industry in Southern Arizona, with an LQ of 1.45. Employment in these laboratories has increased by 25 percent since 2001. Companies in this medical device industry manufacture orthodontic appliances, dentures, crowns, bridges, and other products customized for individual dental patients.

Manufacturers of surgical appliances and supplies compose the other regional specialization. Firms in this industry produce orthopedic devices, prosthetics, surgical dressings, crutches, sutures, and other related products. This growing medical-device-component industry employed 275 workers in Southern Arizona in 2004 and had a 1.26 LQ.

Table 6: Detailed Southern Arizona Bioscience Industry Strengths, 2004

Regionally Specialized and Growing Sectors		
NAICS	**NAICS Title**	**Employment Metrics (2004)**
339116	Dental Laboratories	**Regionally Specialized:** LQ is 1.45 **Employment:** 182 workers **Growth:** Employment increased by 25 percent since 2001
541710*	Physical, Engineering, and Biological Research	**Regionally Specialized:** LQ is 1.37 **Employment:** 734 workers **Growth:** Employment increased by 61 percent since 2001
339113	Surgical Appliance and Supplies Manufacturing	**Regionally Specialized:** LQ is 1.26 **Employment:** 275 workers **Growth:** Employment increased by 6 percent since 2001

Source: Battelle analysis of BLS, QCEW data from the Minnesota IMPLAN Group, Inc.
***Includes only the portion of this industry engaged in relevant life science activities.**

CONCLUSION

The bioscience industry cluster in Southern Arizona is young, but growing rapidly. The sector has begun to develop larger companies like Ventana Medical Systems, which has grown to be one of the largest bioscience firms in the state. The region must recognize this critical juncture in an important development stage and work to nurture its young firms, no matter the size. In its efforts to develop a strong economic base in the biosciences, Southern Arizona has an advantage over most regions in the United States in the form of world-class biomedical university research, premier hospitals, and other strong centers of research. The metropolitan area has an opportunity to leverage these resources with key bioscience industry strengths and favorable trends including:

- Marked employment growth across the total bioscience sector, about 1.5 times the growth of the national sector during the early 2000s.
- A bioscience sector that has significant influence in driving the overall sector at the state level. Southern Arizona has a disproportionately large share of private sector employment in hospitals, medical devices, and research, testing, and medical laboratories.
- A specialized and growing regional life science industry research sector engaged in cutting-edge R&D of new biotechnologies and derivative products. This sector is critical in nurturing innovation and commercial development in the biosciences.
- Continued job growth in the largest major subsector, hospitals.
- A significant firm presence in the production of medical devices and equipment.

Southern Arizona's nonhospital bioscience industry cluster is relatively modest in terms of employment size. Successful firms, however, are growing the sector and have established a strong base in both medical device and equipment manufacturing and in research, testing, and medical laboratories. By focusing on current and emerging strengths, the region has an encouraging economic outlook. The nature of the biosciences allows it to thrive in a region like Southern Arizona, where the existing research base is strong and provides a homegrown lineage of new firms and commercial opportunities. The region has a unique opportunity to leverage these strengths into further building its base in the biosciences.

Southern Arizona's Bioscience Research Base

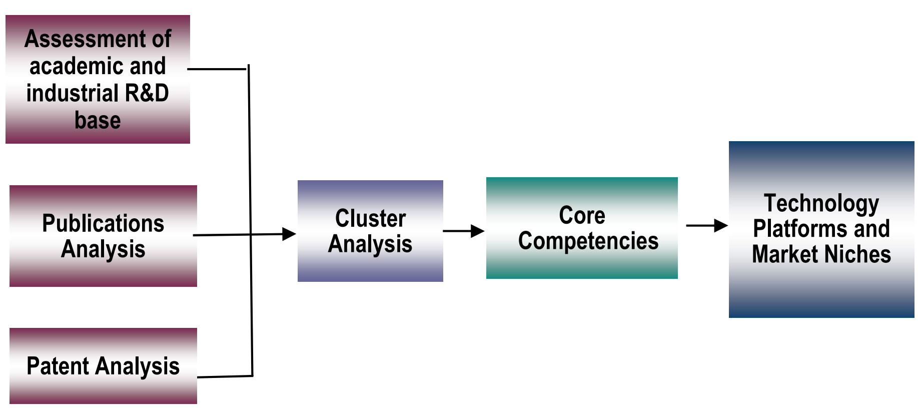
INTRODUCTION

In addition to an understanding of a region's existing industry base, the development of a comprehensive bioscience roadmap requires an understanding of the bioscience-related research competencies within the region's universities and other research institutions. Universities are the national leaders in basic and applied bioscience research, and it is extremely important that bioscience-based economic development strategies be constructed based on an understanding of the capabilities of a state's research universities and associated institutes. Research universities are likewise at the forefront of developing and adopting enabling technologies for advancing bioscience R&D, and it is important to understand the investment in and availability of these tools and resources (such as imaging, instrumentation, advanced materials, combinatorial chemistry resources, etc.) since they contribute so strongly to development pathways. It should also be noted that university core competencies can serve as a magnet to attract commercial research linked to the universities' expertise and specialized focus areas—helping to build a localized environment conducive to specialized bioscience business development and growth.

The biosciences present so many opportunities for the future that it is extremely important for a state or region to understand where its opportunities will lie within a very broad universe of bioscience disciplines, opportunity areas, and possibilities. An extremely small number of states (most notably California and Massachusetts) have such a broad academic and industrial base in the biosciences that they may be able to build on strengths across the board; but, in most states and regions, opportunities will present themselves in more tightly defined fields and the state and its regions must be ready to support and help build capabilities in identified specialized niches.

To identify the specialized niches for Southern Arizona, Battelle employed a methodology that uses the "marketplace" of academe, including peer-driven recognition systems, e.g., publications, citations, and federal fund awards, along with an extensive number of interviews with research leaders, to identify targets of opportunity (Figure 7). Battelle uses its proprietary software, *OmniViz™*, to examine the presence of research "clusters." Using this unique text-analysis tool, along with detailed faculty interviews and a review of publications strengths and funding levels, Battelle documented Southern Arizona's research core competencies and recommended associated technology platforms, which can form the basis for the future growth of Southern Arizona's bioscience sector. The key findings from these analyses are described below. The full analysis is contained in Appendix B.

Figure 7: Methodology to Identify Technology Platforms and Market Niches



UA IN BIOSCIENCE RESEARCH CONTEXT

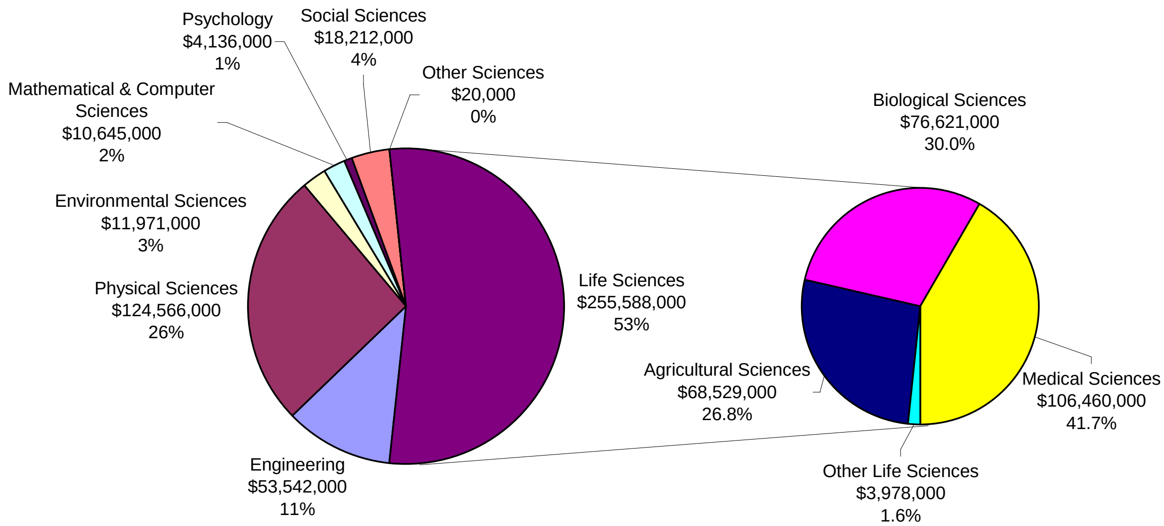
UA is both the leading statewide bioscience research driver in Arizona and the principal driver of bioscience research in Southern Arizona. At the statewide level, UA accounts for 59 percent of all university life science research in Arizona and 62 percent of National Institutes of Health (NIH) funding to Arizona—and is home to the only medical school, pharmacy school, and agricultural school in the state.

For the development of the Southern Arizona Bioscience Roadmap, it is particularly important to consider how UA can further the development of the bioscience cluster within a more focused regional context, while recognizing its critical role as a statewide leader in bioscience research.

The following key points about the UA's bioscience base are important in the overall context of a more detailed examination of its research base.

UA is one of the nation's leading research institutions, and more than half of its research enterprise is found in the life sciences. UA performed $478.8 million of R&D in fiscal year (FY) 2004—ranking it 21st out of more than 700 universities. Slightly more than half (or $255.6 million) of UA's research activity was in the life sciences (Figure 8).

Figure 8: Life Sciences as a Percentage of Total Academic R&D Expenditures for UA, Southern Arizona, by Discipline, FY 2004



Source: National Science Foundation (NSF) Academic R&D Expenditures, 2004; Battelle calculations.

The UA has a balanced portfolio in life science research across medical, agricultural, and biological sciences. Medical sciences account for the largest percentage of total life sciences with more than $100 million in R&D in 2004; but, the region also has strong bases in the biological sciences ($76.6 million) and the agricultural sciences ($68.5 million). Substantial research is also ongoing at UA in closely related fields of chemistry ($11.3 million in 2004), psychology ($4.1 million), and bioengineering ($2.3 million).

This balanced portfolio across medical, agricultural, and biological sciences is also demonstrated in publications activity. In 16 bioscience-related fields, Arizona stands out in publications analysis—as measured by total publications activity and citations per publication. Of these, 10 fall in medical sciences, four in agricultural sciences, and two in biological sciences (text box below).

Areas in which UA has at least 50 papers and citations per publication 25 percent or greater than the nation

- Anesthesia & Intensive Care
- Animal & Plant Sciences
- Clinical Immunology/Infectious Diseases
- Entomology/Pest Control
- General & Internal Medicine
- Medical Research General Topics
- Neurology
- Plant Sciences
- Psychology

Areas in which UA has at least 50 papers and citations per publication 10 to 24 percent greater than the nation

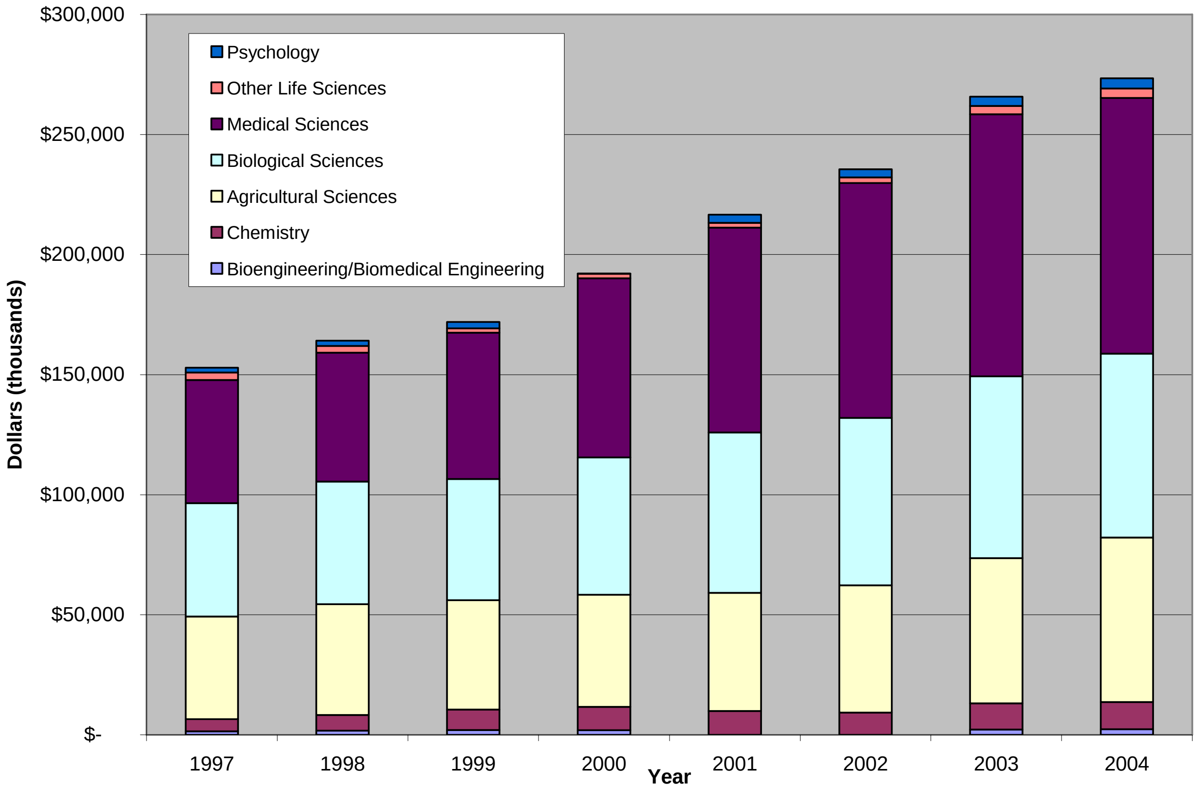
- Cardiovascular & Respiratory
- Food Science & Nutrition
- Gastroenterology & Hepatology
- Medical Research Organs & Systems
- Neurosciences & Behavior
- Oncology
- Pediatrics

Life sciences have been a key generator of growth in UA's research base in recent years. From 1997 to 2004, life science research at UA grew by 77 percent, compared with 68 percent overall growth in the university's research base. In aggregate, 58 percent of the $193 million gain in research activity at UA during this time period resulted from growth in the life sciences.

In medical sciences and agricultural sciences, UA outpaced overall U.S. university research growth from 1997 to 2004. Medical sciences research at UA rose by 108 percent, compared with growth of 103 percent nationally. In agricultural sciences, where UA ranks 13th nationally, the relative growth has been even more impressive, with UA advancing by 60 percent, compared with 37 percent growth nationally in university research from 1997 to 2004. In closely related fields of psychology and chemistry, UA also made substantial gains of 124 percent and 101 percent, respectively, which outpaced national growth in those fields (Figure 9).

Overall, however, UA is still playing catch-up in the biosciences. While UA is increasing its bioscience research as a percent of total university research—from 48 percent in 1997 to 53 percent in 2004—it is still below the national average of 60 percent. Also, despite significant gains in overall medical research funding, UA is still not keeping pace in NIH research funding—the gold standard of biomedical research funding—with its share of national NIH extramural funding dropping from 0.57 percent in 1997 to 0.46 percent in 2005.

Figure 9: Bioscience Academic R&D Expenditures for UA, by Discipline, 1997–2004



Source: NSF Academic R&D Expenditures, 2004; Battelle calculations.

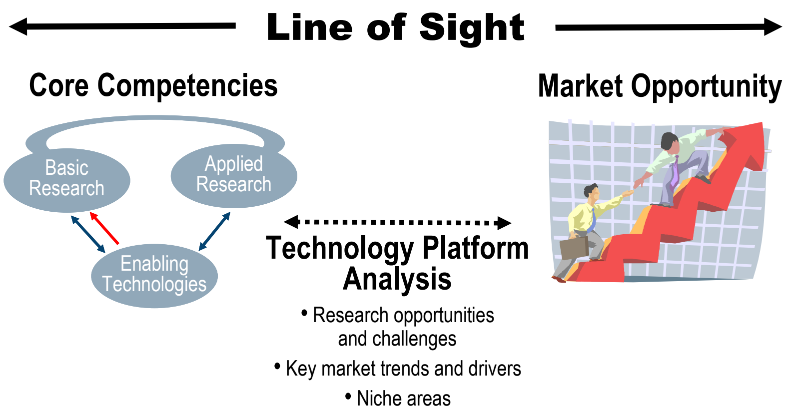
CORE RESEARCH COMPETENCIES

The successful translation of research strengths into economic development opportunities requires the recognition of the importance of “market-driven” processes. The traditional model of commercialization assumes a “research-driven” approach to commercialization. This research-driven commercialization approach proceeds in a pipeline fashion—basic research, major scientific breakthrough, applied research, product development, manufacturing, and marketing. The research-driven approach is too divorced from commercialization and product development and has uncertain economic value. The market-driven approach recognizes that commercialization is a highly interactive process involving close ties between research activities and business development activities. Success depends, as the Council on Competitiveness points out, “on a team effort that includes carefully focused research, design for manufacturing, attention to quality, and continuous market feedback.”[15]

[15] Council on Competitiveness, *Picking Up the Pace: The Commercial Challenge to American Innovation* (Washington, DC: Council on Competitiveness), pp. 9-10.

As seen in Figure 10, the components of a core competency bring together basic research, enabling technology, and applied research activities with a "line of sight" that moves seamlessly to address market opportunities and can form robust technology platforms. Core competencies that lack this linkage and connection to needs and market opportunities offer more limited development opportunities.

Figure 10: Line of Sight Linking Technology Platforms to Core Competencies and Market Opportunities



Identifying Core Competencies

No one single source of information identifies core research competencies and focus areas. Rather, various integrated and complementary analyses are required to identify an institution's current position and areas of focus that may lead or contribute to Southern Arizona's future bioscience growth.

In identifying core research focus areas in the biosciences, Battelle's objective was to identify those fields with an ongoing critical mass of activity and some measure of excellence. Other fields of bioscience excellence may exist within Southern Arizona institutions but in relatively limited pockets. Thus, they offer more limited opportunities but may still contribute in a notable manner.

As defined by Hamel and Prahalad in *Competing for the Future*, a competence is a bundle of skills and technologies, rather than a single discrete skill or technology. It represents the sum of learning across individual skill sets and individual organizational units. According to Hamel and Prahalad, "Core competencies are the gateways to future opportunities. Leadership in a core competence represents a potentiality that is released when imaginative new ways of exploiting that core competence are envisioned."[16]

> "Core competencies are the gateways to future opportunities. Leadership in a core competence represents a potentiality that is released when imaginative new ways of exploiting that core competence are envisioned."
>
> Hamel and Prahalad, *Competing for the Future*

Core competencies guide university-based economic development initiatives in relating to established and emerging markets as technology platforms. Technology platforms draw upon multiple core competencies and have multiple development opportunities in significant market niches. Core competencies also inform how best to gain a position in emerging technologies.

[16] Hamel, G., and C. K. Prahalad. *Competing for the Future*. Harvard Business School Press: Boston, MA, 1994, pp. 90 and 217.

Battelle has developed a rigorous and robust approach to assessing a region's core competencies. It involves (1) an in-depth analysis of patent and federal grant awards, (2) use of specialty technology industry and publications databases, and (3) validation from interviews with industry executives and university officials. It includes both quantitative and qualitative assessments to identify areas of research core competency. The quantitative assessment used statistical information on extramural grants, publications, and patent activities—as well as application of the Battelle-developed *OmniViz*™ software tool to identify research clusters—to develop an understanding of the trends and characteristics of bioscience research within Southern Arizona institutions. The qualitative work included extensive interviews with key administrators, scientists, and researchers across the research drivers found in Southern Arizona organizations and institutions. The goal of the core competency assessment was to identify significant strengths that form a substantial signature for the region around which substantial bioscience-driven economic development can occur.

Quantitative Analysis

Identifies research strengths through statistical analysis that includes the following:

- R&D grant awards
- Publications
- Patents
- Use of *OmniViz*™ clustering analysis of patent and grant awards to identify research and technology areas where both concentration of activity and excellence are demonstrated.

Southern Arizona Core Competencies

Table 7 shows the 17 potential core competencies identified by the quantitative analysis.

Table 7: Broadly Based Core Focus Areas Suggested by Quantitative Analysis of Southern Arizona

Core Focus Area	Federal Research Grants			Publication & Citation Strength	*OmniViz*™ Cluster: Grants	Patents	Academic Reputation	
	NIH	NSF	SDA				Grad	Hosp
Cancer Research	✓				✓			✓
Neurosciences	✓			✓	✓			✓
Plant Sciences			✓	✓	✓			
Insect Sciences			✓	✓	✓			
Agricultural Sciences			✓		✓			
Environmental Eco-sciences		✓	✓		✓		✓	
Pharmacy/ Pharmaceutics	✓					✓		
Basic Molecular & Genomic Sciences	✓	✓	✓		✓		✓	
Asthma/Inflammatory Processes	✓				✓			✓
Bio-Imaging	✓				✓			
Cardiovascular Development/Repair	✓				✓			✓
Bioengineering	✓	✓			✓	✓		
Behavioral Sciences & Community Health	✓	✓			✓			
Basic Physical Sciences	✓			✓		✓	✓	
Applied Math & Biomathematics	✓							
Infectious Diseases	✓			✓	✓			
Diabetes	✓							

Battelle further refined the areas identified in the quantitative analysis based on extensive interviews with more than 100 individuals, including university administrators, faculty, scientists, clinicians, industry executives, and development agencies in the region. The interviews confirmed areas in which Southern Arizona possesses research strengths and highlighted several new and emerging areas of R&D and some key themes that were not readily apparent within the quantitative data. Analyzing both the quantitative and qualitative data, Battelle identified 10 established core competencies, five areas with "significant presence," and two emerging core competencies (Table 8). Areas in which Southern Arizona has a "significant presence" are those that are more focused on one dimension; have lower levels of research activity, clinical expertise, or commercial enterprises; or have a more niche focus of activity.

Established Strengths

Areas in which the region has two of the following:

- A significant number of well-funded researchers, scientists, and/or clinician scientists working in basic, applied, or clinical research
- Recognized clinical expertise
- Applied science R&D assisting critically important current and/or emerging commercial sectors
- A number of commercial enterprises with R&D or production facilities working on the delivery of products or services

Table 8: Southern Arizona's Core Competencies

Established Strengths	Areas with Significant Presence	Emerging
• Cancer Research	• Cardiovascular Development/ Repair	• Diabetes Research
• Neurosciences	• Bioengineering	• Infectious Diseases & Vaccine Development
• Plant Sciences	• Basic Physical Sciences	
• Basic Molecular & Genomic Sciences	• Applied Math & Biomathematics	
• Agricultural Sciences	• Behavioral Sciences & Community Health	
• Insect Sciences		
• Environmental Eco-Sciences		
• Pharmacy/Pharmaceutics		
• Bio-Imaging		
• Asthma & Inflammatory Processes		

It must be recognized that many of the established, significant presence, and emerging strength areas are supported by considerable investment and expertise contained within multiple cross-cutting areas of science and technology. Researchers in basic molecular and genomic sciences, insect sciences, and bio-imaging form distinct clusters of expertise that produce important fundamental and applied discoveries in their own right, but also provide foundational support for the core competencies. Strengths in these areas and the underlying science fabric of Southern Arizona's biosciences must continue to be built in order for core competencies to be sustained, supported and exploited.

It should also be noted that, in modern biosciences, a focus area seldom stands on its own. Rather, just as organisms form complex systems, bioscience itself should be viewed as a complex system of interrelated disciplines and areas of study that support and assist in advancing one another. For this reason, NIH and similar funding organizations are focusing increasing grant-making attention on interdisciplinary institutes, centers, and research teams. As such, the formation of focused interdisciplinary teams, centers, and institutes should be an institutional imperative for success in accessing large-scale federal grant funding.

The links that exist and form among strength areas are critical to the emergence of bioscience core competencies in Southern Arizona. As in any system, a change in one of the parameters (strength areas) is likely to affect the operation of others. For example, a center for the support of biosensor development may increase the attention of various medical, veterinary, and agricultural subdisciplines on applications of advanced sensors in their work. Likewise, a center for the study of novel drug-delivery methods might stimulate interdisciplinary teams to form around applications to cancer, cardiovascular disease, or neuro-degenerative diseases.

BIOSCIENCE TECHNOLOGY PLATFORMS FOR SOUTHERN ARIZONA

Purpose and Process of Technology Platforms

The purpose of identifying a region's research strengths and core competencies is to identify strategic areas of focus that offer the greatest opportunity for near-term development—Battelle uses the term "technology platforms" to describe these. Technology platforms serve as bridges between research core competencies and their use in commercial applications and products. As such, platforms are highly translational in nature—working to facilitate strong movement of ideas and innovations from basic science discoveries to applied technologies and practices.

The technology platform process can be understood through a systems approach in which innovations flow from core competencies resident in a region's research institutions, via the platforms, to commercial products, which then find their way into markets. These technology platforms are intended to be robust and evergreen and to integrate several of the core competencies to produce a continuous flow of innovative, and perhaps disruptive, technology or products. Platforms also serve as forums for building strong interactions and relationships between academic researchers and their counterparts in industry.

Criteria for Selecting Technology Platforms for Development

An area of focus must

- Build on existing strengths
- Have a base of related emerging or established commercial activity
- Provide opportunity to leverage state's comparative advantages
- Have significant product market potential
- Link to or reinforce other bioscience strengths and core competencies.

The areas of greatest opportunity for developing technology platforms are those in which a region has

- Existing research strengths;
- Bases of commercial activity emerging or established within the region with genuine opportunity to create a base in the near future;
- Distinct opportunities to leverage the region's comparative advantages to create competitive marketplace advantages
- Significant product market potential; and
- Links to, or reinforcements of, other bioscience strengths and core research competencies, thereby helping to enhance other fields as a platform expands.

Three Technology Platforms for Southern Arizona

In addition to the existing statewide competencies and platforms in Table 8, the Battelle team identified the following three unique technology platforms that build upon Southern Arizona's core research competencies and can be sources of innovative technologies and products for its economy:

1. Molecular Targeted Therapeutics and Diagnostics
2. Preventive Medicine
3. Insect Sciences.

Each platform is described below.

Molecular Targeted Therapeutics and Diagnostics

Modern post-genomic sciences provide the UA with the ability to develop disease diagnostics and therapeutics through identification of specific molecular targets. At the forefront of molecular target identification, the Arizona Cancer Center has extended this expertise into the discovery and development of novel anticancer therapeutics designed to positively impact the identified molecular targets. Building from the strong work in cancer at UA, multiple groups, including the Arizona Cancer Center at the College of Medicine, BIO5, College of Pharmacy, and Department of Chemistry, are joining to promote the concept of a molecular targeted therapeutics and diagnostics focus.

While cancer is an important initial focus of expertise for Southern Arizona in molecular targeted therapeutics, a push is also emerging toward extending this expertise into molecular therapeutics discovery and development for neurological therapeutics applications. The formation of a dedicated platform in molecular targeted therapeutics in Southern Arizona is supported by progress already made by UA faculty in developing technologies and companies to commercialize these technologies. Key product opportunities will include both molecular diagnostic tools and tests, and drugs and other therapeutic agents. This area also benefits greatly from the bio-imaging strengths found at UA, particularly in examining molecular and cellular impacts of new therapeutics and broadly in developing diagnostics.

By building upon this UA program, Arizona will benefit statewide in its bioscience initiatives since targets for therapeutics may be identified within multiple research institutions in the state (such as TGen, Barrows, and Arizona State University [ASU]). Currently, while great investment has been made in Arizona in defining disease at the molecular level, which can then be translated into molecular biomarkers, the next step toward producing therapeutics to impact these targets has not been the subject of investment. UA clearly has the basic elements required to drive development of a significant platform presence in the discovery and development of molecularly targeted drugs; by building upon this foundation further, Arizona will be far better positioned to capitalize on its growing base of identified molecular markers.

As envisioned by leaders in this field at UA, a campus-wide program in molecular targeted therapeutics would interface with molecular diagnostics and imaging to form a platform that would greatly facilitate the progress of clinical translational programs in Arizona. The physical infrastructure for ramping up molecular targeted therapeutics is nearing completion at the university, with BIO5, the Chemistry Department, and the new Medical Research Building having dedicated significant space to developing this platform.

Gaps and additional investment requirements will need to be addressed to achieve the rapid platform development that Southern Arizona could see in this arena. UA will need funds to recruit a recognized program director for drug discovery and development, together with several key faculty hires to reinforce complementary areas including medicinal chemistry, synthetic organic chemistry, and clinical pharmacology. Support services and staffing for Phase I trials will also need to be addressed. Additional investment will also be required in support of boosting training programs and fellowships in drug discovery and development at UA.

Investing in a molecular targeted therapeutics platform for Southern Arizona will leverage the existing expertise in cancer, help capitalize further on the considerable new space supporting therapeutics discovery and development at the university, and provide a natural pathway for translating the understanding of disease at the molecular level that is the focus of many Arizona bioscience research institutions.

Preventive Medicine

Preventive medicine aims at preventing disease and promoting health. Through epidemiologic analysis, genomic analysis, phenotype analysis, and the tools of public health, preventive medicine is "coming of age"—providing deeper understanding of pathways to disease prevention. As the field progresses and expands, there will be widespread application for the translation of R&D discoveries into commercializable strategies, products, and technologies. UA's key strength in bio-imaging will enable preventive medicine to have a particularly strong technology backbone.

In Southern Arizona, expertise extends from epidemiology and public health analysis to genomic and molecular studies that may lead to personalized medicine approaches to preventive medicine. A preventive medicine platform can bring together a highly diverse, interdisciplinary group of high-profile researchers conducting work in behavioral sciences and community health, basic molecular and genomic sciences, plant and natural products, and specific disease focus areas. Southern Arizona is uniquely positioned to bring multiple pathways of discovery together to produce novel strategies and products. The region is also well positioned for taking holistic approaches to disease prevention that consider environmental factors, sociological factors, and genetics.

Southern Arizona has the opportunity to build its early preventive medicine work around the cancer focus area. The Arizona Cancer Center in the College of Medicine is the leading recipient of federal research funding directed at cancer prevention and control and forms the basis for further expansion in this area.

From a product pathway standpoint, there will be demand for the development of advanced identification and preventive approaches, such as chemopreventive agents in cancer—agents targeting genetic, molecular, phenotypic, biochemical, and immunologic markers. Similar opportunities will occur in other biomedical focus areas for Southern Arizona around neurological and neurodegenerative diseases, respiratory disorders, and diabetes. Furthermore, commercial opportunities will likewise occur in diagnostic tools and technologies and in analytical techniques and technologies. Work in infectious disease prevention and vaccine technologies will also be a natural fit with this platform.

Insect Sciences

UA is home to the Center for Insect Sciences (CIS), an operating division under the Arizona Research Laboratories (ARL). CIS is probably the world's leading collaborative center for interdisciplinary research using insects; it currently contains more than 130 faculty members from 15 departments. The center also has collaborators from both ASU and Northern Arizona University; but, by far, the main cluster of scientists is within UA.

The insect sciences platform is best viewed as "cross-cutting" because its applications and areas of study are quite broad and applicable to advancing a broad range of other Arizona and Southern Arizona bioscience platforms. The diversity of faculty engaged in CIS R&D points to the multidisciplinary nature of the platform, with participants from electrical and computer engineering; mechanical engineering; aeronautical engineering; human physiology; neuroscience; molecular, cellular, and developmental biology; evolutionary biology and ecology; and the more traditional entomological sciences.

Applications for CIS cross-disciplinary expertise are also multidimensional, including opportunities in the following:

- **Engineered Products**—This includes products using insect models, insect-based structures, or insect-based biomaterials to produce novel devices, prostheses, and biomaterials for biomedical and nonbiomedical applications. Faculty within the insect sciences program are already moving along the engineered products pathway with initiatives in neuromorphic engineering of visual prosthetics, development of visually intelligent autonomous robots, and optics design for bioimaging applications.
- **Agriculture and the Environment**—This includes products and solutions to agricultural pest control, together with control methods and technologies for endemic urban/household insect pests. In addition, insect sciences expertise can be leveraged to investigate plant-insect interactions in relation to pollination and agricultural challenges peculiar to Southwest agricultural and natural ecosystems. There is also considerable potential for development of insects as sensors for use in climate-change and genetic-drift environmental monitoring applications.
- **Infectious Disease Vectors—**This includes technologies and solutions targeting insect hosts for zoonotic infectious diseases. A cross-link exists to the preventive medicine platform.
- **Expansion in Basic Sciences and Biomedical Research**—In both basic and applied research, great potential exists for using insects as model organisms for advancements in developmental biology, evolutionary biology, neurobiology, and other related bioscience disciplines. Some of the specific areas of application being advanced at UA include genetic screening for cerebral defects; models of muscle innervation and neurodegenerative disease; mechanisms of sensory perception; models for learning, memory, and aging; and Alzheimer's disease models.

Through platform status, the deep expertise in insect sciences in Southern Arizona can be directed toward specific focused projects—in terms of both technologies from the insect sciences platform itself and support to advancements in other platforms such as neurosciences, bioengineering, bioagriculture, and infectious diseases.

Contributions of Southern Arizona Institutions to Statewide Bioscience Platforms

Previous Battelle reports have profiled recommendations and conclusions regarding statewide bioscience platforms for Arizona.[17] This section of the report for the Southern Arizona Bioscience Steering Committee concentrates on outlining the particular areas of R&D focus, within Southern Arizona institutions, that directly relate to the statewide platforms. Based on the review of quantitative data and in-depth interviews conducted with research leaders in the potential platform areas, the platform focus areas listed in Table 9 are key strengths for Southern Arizona.

[17] "Flinn Reports." Flinn Foundation Web site, http://www.flinn.org/bio/reports.cms#bioscience.

Table 9: Platform Strengths of Southern Arizona

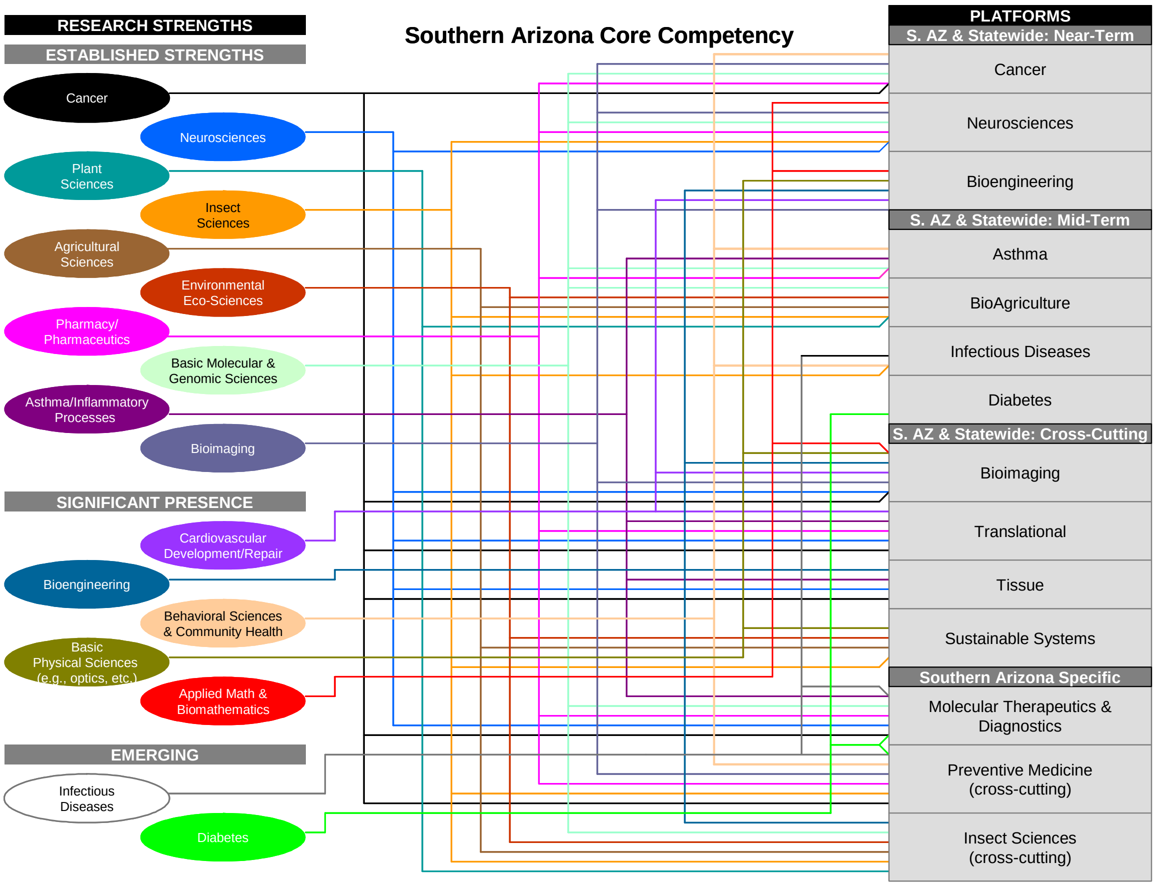
Statewide Platform	Southern Arizona Engaged Institutions	Key Contributions and Focus Areas
Cancer	UA	• Comprehensive Cancer Center, College of Medicine • Cancer prevention and control • Molecular target identification • Cancer therapeutics discovery and development, including developed drugs in clinical trials • GI cancer and skin cancer core competencies • Cancer imaging • New cancer center being developed to increase clinical research capacity and access • Noted program in cancer therapeutics development • Multiple commercial entities started by cancer faculty in drug discovery and development
Neurosciences	UA	• Neurodevelopment and model systems focus, with strong link to leading program in insect sciences • Neurodegeneration and aging • Movement disorders • Pain • Vision (especially macular degeneration) • Cognition, memory, and learning • Developing program in neurotherapeutics contained within BIO5
Bioengineering	UA	• Cardiovascular bioengineering (artificial hearts and bridge to transplant technologies) • Small but growing work in orthopedic materials and devices • Growing focus in nanotechnology and BioMEMS • Signal processing and sensor development • Telemedicine, teleradiology, and telepathology • Stem-cell-based regenerative medicine • Strong working relationship with co-platform in bioimaging technology and applications • Emerging push in biomaterials and biologically inspired materials for which there is a small local industry base
Asthma	UA	• Home to internationally known Arizona Respiratory Center, College of Medicine • Asthma biomarker identification • Cellular and molecular mechanisms of asthma • Population/epidemiologic studies and analysis • Highly ranked clinical care and treatment programs

Table 9: Platform Strengths of Southern Arizona (continued)

Statewide Platform	Southern Arizona Engaged Institutions	Key Contributions and Focus Areas
Bioagriculture	UA	• Broad and deep expertise in plant biology, molecular biology, and structural and functional plant genomics (including whole plant genome sequencing) • World leaders in plant epigenetics • Expertise in RNAi and in chromatin structure and gene regulation • Focus on plant stress and drought tolerance for agricultural applications • Growing expertise in closed environment agriculture—directly relevant to growth of horticulture industry and biopharming applications • Emerging work in functional foods and nutraceuticals
Infectious Diseases	UA and Southern Arizona VA Medical Center	• Strong microbial genomics • Valley Fever Center of Excellence at College of Medicine • Emerging focus in Dengue fever • Natural linkage to insect sciences expertise in insect-borne diseases
Diabetes	UA	• Growing area of research focus for UA College of Medicine, with new strategic hires • UA strengths in obesity and weight control • Operate the Arizona Diabetes Virtual Center of Excellence—a comprehensive program for diabetes prevention, assessment, and management using the Arizona Telemedicine Program Network
Bioimaging	UA	• Strong support for bioimaging based on institutional track record as world leader in optics R&D • Gamma ray imaging and nuclear medicine • Optical imaging and endoscopic imaging • Image and signal processing and analysis, with strong backup support through world-class applied mathematics program • Deep applied programs in cancer imaging and neurodegeneration/aging imaging • Supported by existing industry cluster in Southern Arizona's "Optics Valley", including successful spin-out companies
Translational	UA	• Key emphasis area of UA BIO5 • Direct translational activities occurring in cancer therapeutics, cardiac medical devices, and bioimaging technologies
Tissue	UA and Southern Arizona VA Medical Center	• Multiple tissue storage facilities, including operations at UA and VA
Sustainable Systems Note: This is an Arizona development platform separate from the bioscience platform initiatives	UA	Related expertise in the following focus areas: • Environmental toxicology • Environmental engineering • Evolutionary and developmental biology • Climate change and global monitoring • Hydrology, water resources, and arid environments • Ecological impacts of transgenic plants • Role of insects in sustainable ecological systems

Figure 11 shows the relationship between Southern Arizona's research strengths and both the state's and Southern Arizona's technology platforms.

Figure 11: Relationship Between Southern Arizona's Research Strengths and Arizona and Southern Arizona Technology Platforms



Market Analysis

The ultimate goal for Southern Arizona in supporting the development of bioscience platforms is economic development. R&D, in and of itself, ***is*** economic development in that millions of dollars flow into the region each year from federal and other external funding sources to support research. These dollars, in turn, create jobs and income for persons in Southern Arizona in, and related to, the R&D sector. **The goal of technology-based economic development, however, is to follow an integrated model whereby local research feeds a local commercialization and production cluster, thereby capturing increased value-added economic gains for the region from its R&D work.**

Given the increasing regional economic returns from the commercialization of R&D innovations, it is highly important that markets and commercialization opportunities related to each platform be considered during platform development. Tables 10 through 12 serve to integrate R&D strength areas with applications and potential products and general market characteristics. It is evident that each platform focus area addresses multibillion-dollar markets, providing considerable opportunity for growing the regional bioscience economy around these core competencies.

Table 10: Molecular Targeted Therapeutics and Diagnostics Technology Platform

Basic Research	• Molecular biology • Structural biology • Molecular modeling • Biochemistry and signaling
Enabling Technology	• Pharmaceutical science • Clinical pharmacology • Structural and functional imaging • Small mammal transgenics
Technology Platform	Molecular Targeted Therapeutics and Diagnostics
Applications and Products	• Molecular diagnostic tools • Molecular therapeutics (drugs)
Markets	• The global market for prescription drugs is predicted to grow 6% to 7% in 2006 to a total size of $640 billion to $650 billion (IMS Health). The U.S. market represents fully 43% of global pharmaceutical sales, and is expected to grow faster at 8% to 9%. • Cancer drug sales (an area in which Southern Arizona has considerable strengths) are projected to reach $55 billion in 2009, compared with the $24 billion in 2004 (IMS Health). • By 2009, the top drug categories are projected to be: 1. Oncology ($55 billion) 2. Cholesterol ($38 billion) 3. Antidepressants ($26 billion) 4. Stomach ulcer treatments ($26 billion) 5. Hypertension drugs ($24 billion) 6. Antipsychotics ($20 billion) 7. Platelet inhibitors ($18 billion) 8. Anemia drugs ($18 billion) 9. Osteoporosis ($16 billion) 10. Anti-epileptics ($15 billion) (IMS Health). • Molecular diagnostics markets overlap with markets for non-molecular diagnostic technologies in the in vitro diagnostic market and are less well defined than those for pharmaceuticals. In the year 2005, the global market for molecular diagnostics was worth $6.5 billion, representing approximately 3.3% of the total diagnostics market and approximately 14% of the in vitro diagnostic market (Jain PharmaBiotech 2006). • The molecular diagnostics market will expand to $12 billion by 2010 and $35 billion by 2015. A major portion of it can be attributed to advances in genomics and proteomics. Biochip and nanobiotechnology are expected to make a significant contribution to the growth of molecular diagnostics (Jain PharmaBiotech 2006).

Table 11: Preventive Medicine Technology Platform

• Basic Research	• Genetics and genomics • Molecular biology • Immunology • Epidemiology • Public health • Biostatistics, mathematics, and modeling
• Enabling Technology	• Rapid genetic testing • Bioimaging • Animal research facilities • Pharmaceutical science • Clinical pharmacology
Technology Platform	Preventive Medicine
Applications and Products	• Diagnostics • Preventive drug therapies • Gene and cellular therapies • Vaccines • Personalized medicine clinical services • Public health analytical tools and technologies
Markets	• Preventive medicine, from a product perspective, will include a broad range of clinical diagnostics, genetic tests, drug therapies, and nondrug therapeutics (e.g., cellular transplantation, gene therapy). Preventive diagnostics and therapeutics represent an extremely large market opportunity, since preventive steps may be applicable to almost every person. Since the global market just for current prescription drugs is approximately $650 billion, it is likely that preventive drugs and diagnostics could quite rapidly become $100 billion+ markets. The potential market for personalized clinical preventive care will also be very large and represents a subregional opportunity since much care, counseling, and related analytical services will be provided locally. • The more individually focused, personalized approaches contained in targeted preventive medicine will likely favor smaller niche companies, producing custom products (as opposed to major pharmaceutical companies with blockbuster drugs). Thus, the business development opportunities, and associated localized economic impacts, are likely quite high for preventive medicine. • Vaccines are also a preventive medicine component. The vaccine market represents a significant growth opportunity. Industry estimates vary; but, Merrill Lynch suggests the worldwide market could be worth $10 billion by 2006. Much of the predicted growth of the vaccines market is expected to come from the introduction of new vaccines, either against diseases for which no vaccine currently exists or as second-generation products to replace existing vaccines.

Table 12: Insect Sciences Technology Platform

Basic Research	• Entomology • Developmental neurobiology • Structural biology • Comparative anatomy • Engineering disciplines • Chemistry and chemical engineering
Enabling Technology	• Structural and functional imaging • Insect breeding facilities • Engineering facilities
Technology Platform	Insect Sciences
Applications and Products	• Insect-inspired engineered materials • Insect-inspired engineered systems • Insect-based materials • Agricultural and urban pest control products
Markets	• It is very difficult to attach market figures to many of the potential products that could result from insect science discoveries. • In terms of "green" materials, the global market was estimated to stand at $6.1 billion in 2005 and is expected to reach $8.7 billion by 2010—an average annual growth rate of 7.4% (Electonics.ca Publications). • Nanomaterials, as an example of an emerging materials market, accounted for $9.4 billion in 2005 and more than $10.5 billion in 2006, growing to about $25.2 billion by 2011—an average annual growth rate of 19.1% between 2006 and 2011 (Electonics.ca Publications). • Smart materials, another emerging materials category, have also built up markets quite rapidly. The worldwide smart materials market is estimated at $8.1 billion in 2005 and is expected to rise at an average annual growth rate of 8.6% to $12.3 billion in 2010 (Electonics.ca Publications). • Chemicals for insect control (insecticides) comprise a substantial global market. In 2000, the global insecticide market was estimated at $8.7 billion, with the United States comprising $3.1 billion. The $3.1 billion in insecticides sold in the United States are split quite evenly between those used for agricultural applications and those used in home and garden applications (U.S. Environmental Protection Agency).

SUMMARY

UA is the principal driver of bioscience research in Southern Arizona as well as statewide. Its bioscience core competencies are numerous, including many areas of both medical and agricultural sciences. These core competencies are the foundation around which Southern Arizona can build its bioscience cluster. Figure 12 shows the university's research strengths and how they relate to development opportunities.

Having established in this and the previous section of this Roadmap that Southern Arizona has a strong emerging R&D base in the biosciences, the next section of this report examines the competitive position of Southern Arizona in the biosciences and identifies factors that should be addressed to ensure that the region can exploit its research strengths to achieve its economic development goals.

Figure 12: Potential Development Targets for Southern Arizona

Bioengineering, Cardiovascular R&D, Bioimaging, Biomath, Optics and Optical Sciences	→	**Medical Devices, Imaging Equipment and Materials**
Cancer, Neurosciences, Respiratory Diseases, Diabetes, Pharmacology, Pharmacy, Chemistry, Imaging, Genomics and Proteomics	→	**Molecular Therapeutics and Diagnostics**
Insect Sciences, Entomology, Engineering, Computer Science, Neurosciences, Infectious Diseases, Plant Sciences, Ophthalmology, Biomath	→	**Insect-Inspired Technology**
Plant Sciences, Genetics, Genomics and Epigenomics, Proteomics, Nutritional Sciences, Plant Physiology, Plant Pathology, Controlled Environment Ag, Insect Science	→	**Plant Genomics and Associated Biotechnology**

Situational Assessment

It is clear that Southern Arizona has an emerging industrial base and a strong research base on which to continue to build its bioscience economy, and strategic areas for future development have been identified. But, this is not the only region seeking to grow its bioscience sector. States and regions across the United States are investing significant resources in the biosciences.

To succeed, Southern Arizona must build upon its competitive advantages as a location for bioscience companies and address any competitive disadvantages. The Battelle project team interviewed public and private leaders, bioscience company chief executive officers (CEOs), entrepreneurs, venture capitalists, government officials, and service providers to get their assessment of Southern Arizona as a location for bioscience development. The text box at right summarizes the region's key competitive advantages and the challenges that will need to be addressed to accelerate the growth of Southern Arizona's bioscience economy.

Competitive Advantages

- University of Arizona
    - R&D Base
    - Students and Graduates
    - Highly rated Entrepreneurship Program
- Entrepreneurial environment
- Core base of bioscience start-ups and established companies
- Quality of life that appeals to many talented individuals
- Base of experienced retirees

Challenges

- Retaining faculty and staying at the cutting edge of bioscience research
- Not enough being done to commercialize technology generated by U of A
- Small clinical science base, small medical school
- Insufficient interaction between large and small bioscience companies and between companies and the U of A
- Perception of quality of K-12 education
- Insufficient sources of capital

There was general agreement that Southern Arizona has three differentiating drivers on which to build its bioscience base:

1. **A culture of entrepreneurship.** Southern Arizona has a strong history of creating bioscience-driven firms. Some of these have been developed around technologies developed by UA faculty and researchers, particularly those associated with the Cancer Center; others were created when some of these initial firms generated additional spin-off companies. The region has identified successes such as Ventana and Sanofi-Aventis, among others, something few other regions in the country have to the extent that this region can.
2. **A deep research base.** UA's and UMC's strengths in the core competencies and technology platforms identified in this report show how critical UA is to the state's and region's research enterprise. A pioneering UA has emphasized interdisciplinary research and partnerships since the early 1970s and is ideally positioned to respond to the opportunities and challenges that face the biosciences.
3. **A strong quality of life.** The region's quality of life attracts and retains talent, researchers, and enterprises. Reasonable costs of living, relatively smooth traffic flow, cultural amenities, and other factors are all rated positively by residents of Southern Arizona.

To take advantage of these drivers, several **strategic directions** are suggested, based on the strengths and opportunities found in the region:

- ***Ensure that UA continues to be Arizona's strong research engine in the biosciences, particularly in those platforms of strength or emerging strength identified in this report.***
- ***Increase the region's ability to capture innovation from this research base and its existing bioscience enterprises and other industries in order to become a strong center of technology entrepreneurship, which can translate into new firms, increased wealth, and high-wage jobs.***
- ***Focus the region's economic development approach on recruiting bioscience-related firms around the region's strengths in its technology platforms and its existing industry base.***
- ***Employ the region's civic leadership to recognize and engage the entire population in a technology-driven economic future, a key component of which is the biosciences. The biosciences represent a technology convergence opportunity as well, building on the region's strengths in optics and related information technology (IT) areas.***

LEVERAGING THE REGION'S UNIQUE ASSETS

Southern Arizona has a number of assets on which to build its bioscience base, including the following:

- A pioneering College of Sciences at UA that has emphasized interdisciplinary research and partnerships for many years and has made a commitment to integrated bioscience efforts
- Major nationally ranked professional programs and schools, including pharmacy, medicine, business, agriculture, and the life sciences
- A major new technology anchor or collaborator with the drug and pharmacy industry in C-Path
- Initiatives to address some of the gaps found in this report such as a bioscience research park
- A history and track record of success in growing bioscience firms from start-up as well as through acquisitions and mergers—several of which have grown into large, established firms
- A large pool of educated graduates coming from the region's community college and the UA, which can fuel firm innovation and growth.

These assets can position Southern Arizona well for a stronger economic future where the biosciences are an important component of a more diversified economy, but only if these assets become better networked and leveraged and if the region becomes more actively committed to the bioscience sector.

A Vision for Southern Arizona

Ten years from now, in 2016, the world should characterize Southern Arizona's standings in the biosciences in the following ways:

Arizona Bioscience Roadmap: *Arizona is the leading southwestern state in selective bioscience sectors, built around world-class research, clinical excellence, and a growing base of cutting-edge enterprises and supporting firms and organizations.*
Southern Arizona Bioscience Roadmap: *Southern Arizona is one of the nation's recognized bioscience centers, driven by its strengths of a talented workforce, a cutting-edge research university, and a global center for bioscience innovation. Its civic leaders help drive the bioscience economy, mobilizing leadership committed to collaboration, results, and economic growth.*

Achieving this Vision

Southern Arizona's vision will not become a reality unless the 4 Cs—commitment, collaboration, connections, and communications—become the day-to-day mantra of how this Southern Arizona Bioscience Roadmap is implemented. Success in achieving the Vision will require

- **Committed** public and private sector leadership working to support bioscience-driven technology development, led by champions in industry, universities, and government.
- **Collaboration** across institutions and organizations. This has already been demonstrated since the release of the Arizona Bioscience Roadmap in 2002; but, much more remains to be done.
- More prevalent and effective management and research connections and communication across industrial, governmental, and educational sectors.

Strategies and Actions

The strategies proposed for Southern Arizona focus on leveraging the region's assets—its talent base, research base, and its core of established companies—to attract, create, grow, and strengthen its critical mass of research in focused areas while at the same time continuing to achieve a critical mass of bioscience firms. The region's bioscience industry base is growing, but it is still small. Specific strategies include the following:

- **Strategy One:** Continue to build Southern Arizona's research strengths around bioscience technology platforms.
- **Strategy Two:** Continue to build a critical mass of bioscience firms in Southern Arizona.
- **Strategy Three:** Build a talent base that captures and retains Southern Arizona's human resources.
- **Strategy Four:** Address and maintain a business climate supportive of the biosciences and their growth in Southern Arizona.
- **Strategy Five:** Educate, inform, and spur to action opinion leaders and the general public on Southern Arizona's future in the biosciences.

These five strategies and the 17 actions proposed to achieve them are outlined in Figure 13 and Table 13. It is anticipated that 90 percent of these actions would be implemented over a 5-year time period.

Figure 13: Overview of Strategies and Actions

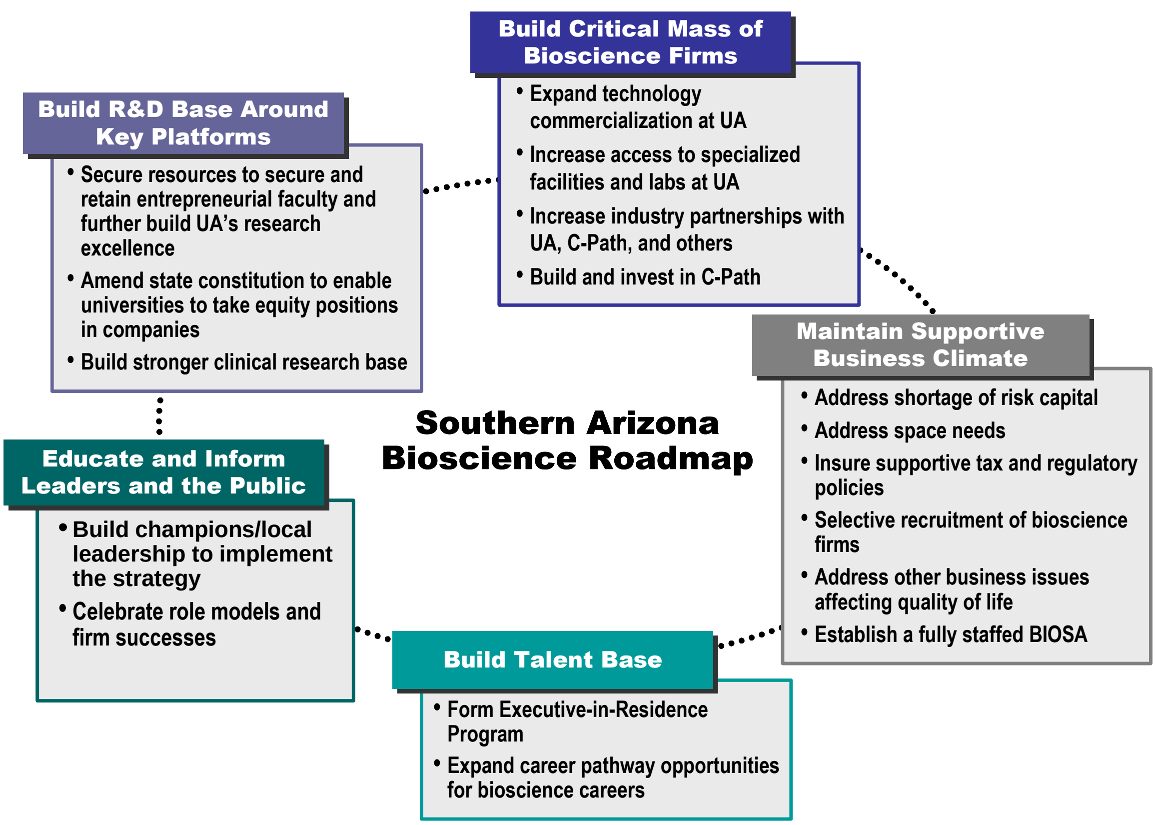


Table 13: Summary of Proposed Strategies and Actions

Objective	Action
Strategy One: **Continue to build Southern Arizona's research strengths around bioscience technology platforms**	Secure additional state, federal and private resources to fully utilize facilities, secure and retain entrepreneurial faculty, and further build the University of Arizona's research excellence Amend Arizona's State Constitution to enable research universities to take equity from licensing in addition to royalties Build a stronger clinical research base to position UA, UMC, and industry for translational research, linking discoveries with patient care and disease treatment and prevention (NIH Clinical and Translational Science Award [CTSA] planning grant)
Strategy Two: **Continue to build a critical mass of bioscience firms in Southern Arizona**	Strengthen and expand the region's technology commercialization efforts both at UA and for entrepreneurs outside the university Increase awareness of and access to specialized facilities and laboratories at UA Increase industry partnerships with UA, C-Path, and other research institutions in the state through matching grants, industry fellows, clinical trials, and other approaches Continue to build and invest in C-Path as an additional technology anchor for industry linkages to the region
Strategy Three: **Build a talent base that captures and retains Southern Arizona's human resources**	Form an executive-in-residence program to increase the supply of readily available serial entrepreneurial talent available to support and place in newly formed bioscience enterprises Expand career pathway opportunities for students to pursue careers in the biosciences
Strategy Four: **Address and maintain a business climate supportive of the biosciences and their growth in Southern Arizona**	Address shortage of risk capital for biosciences in region and state through a BioSeed Fund, angel funds, and recruiting of out-of-state risk investors Address space needs of bioscience firms through combination of incubator and accelerator space and development of a bioscience-focused research park. Ensure region's and state's tax and regulatory approaches are supportive and conducive to the growth of bioscience firms Develop strategic targets of opportunity in the biosciences for recruitment of firms and focus economic development efforts on such targets Address other business and quality-of-life issues affecting bioscience firms and their workers Fund staffing for BIOSA so it can offer expanded networking and other functions as well as serve as an effective advocate for the biosciences in Southern Arizona and a partner with the Arizona BioIndustry Association (ABA) statewide

Table 13: Summary of Proposed Strategies and Actions (continued)

Objective	Action
Strategy Five **Educate, inform and spur to action opinion leaders and the general public on Southern Arizona's future in the biosciences**	Build champions/local leadership within industry, the public sector and higher education to implement this Southern Arizona Bioscience Roadmap Celebrate role models and entrepreneurial and firm successes as part of a regional and statewide public education and awareness effort in conjunction with the statewide brand (Biozona) within and outside the state

STRATEGY ONE: CONTINUE TO BUILD SOUTHERN ARIZONA'S RESEARCH STRENGTHS AROUND ITS BIOSCIENCE TECHNOLOGY PLATFORMS

Secure additional state, federal, and private resources to fully utilize facilities, secure and retain entrepreneurial faculty, and further build UA's research excellence

Rationale:

The UA represents a strong portion of the existing bioscience research base of Arizona, accounting for 59 percent of Arizona's life science research and 62 percent of its NIH funding. In completing the *Arizona Bioscience Roadmap*[18] in 2002, Battelle's core competency and technology platform analysis identified many key areas for near- and mid-term focus for the state as it builds its bioscience research and industry base. In almost every case, these research strengths were built around UA's research depth and expertise. In the core competency and platform identification section of this report, several Southern Arizona technology platforms were identified, all driven by UA. Not surprisingly, these same Southern Arizona strengths also continue to set the stage for statewide strengths, relying heavily on the depth, reputations, and research resources represented by UA.

Since the *Arizona Bioscience Roadmap* was completed in 2002, the Arizona Legislature approved $440 million in spending on research facilities at the state's three public research universities; these investments are now being completed. The vast majority of these facilities are directed at the biosciences and the cross-cutting areas essential to the biosciences, such as imaging and other IT areas. As these facilities are completed, the state must invest research dollars to further build the depth of expertise to fully capture the intellectual value these facilities represent. This is particularly true with respect to the state's core technology platforms. To do this will require the Arizona Legislature and Governor to request operating in addition to capital funds from the state budget.

That the Governor and Legislature provided $35 million in the 2006 session for the newly formed Science Foundation Arizona is an important first step, but not the last. While private individuals pledged $100 million to Science Foundation Arizona along with $50 million from the Piper Foundation, only the first year was funded. The 2006 session also provided the state's research universities with additional funds to retain and recruit faculty in priority areas, which will continue the momentum in this area.

[18] *Platform for Progress: Arizona's Bioscience Roadmap*. Prepared for the Flinn Foundation by Battelle TPP. December 2002.

If Arizona wants to be competitive in a sector that is receiving increasing levels of funding from other states, this state support must continue. Additional state funding is required to ensure implementation of the *Arizona Bioscience Roadmap*, including additional research funding for UA. The magnitude of this state support is suggested by previous work funded by the Flinn Foundation, which provided grant support to Battelle to assist in completing science program plans for the three near-term platforms identified in the *Arizona Bioscience Roadmap*—bioengineering, cancer therapeutics, and neurosciences—by working in conjunction with faculty leaders from the three research universities and the state's teaching hospitals and medical centers in 2003 and 2004. These business or program plans for the three near-term Roadmap technology platforms determined that an additional $500 million or more is needed for the state to excel nationally and internationally just in these areas—areas in which UA excels. While a similar amount has not been calculated for the mid-term platforms, which are only now getting underway in 2006, doubling the amount to a total of $1 billion may be a reasonable estimate.[19]

Proposal:

The State of Arizona government must continue to provide and significantly increase its financial support for research—a basic prerequisite to building the state's bioscience base—to achieve research excellence and commercial development aligned with the state's existing and emerging industry strengths.

This support must be appropriated flexibly for equipment, and faculty recruitment and retention, and to enable young investigators to gain experience to secure subsequent federal and industry funding. It is estimated that each $1 of state funding will leverage at least $6 of investment from other sources.[20] Initial funding for Science Foundation Arizona continues the state's significant movement in this direction through Proposition 301 and the cigarette tax funds for research administered by the ABRC, both of which occurred prior to establishment of Science Foundation Arizona. More funding will be needed in the future, and UA and its competencies/platform base should be recognized in the distribution of these additional state funds. The state needs to invest in its existing state strengths, many of which are located at UA to attract federal dollars. The state should be positioned to take advantage of these strengths and be prepared to further build national and international excellence at Arizona universities by continuing to invest in these areas that can leverage federal and industry support.

In addition, Arizona's federal Congressional Delegation needs to advocate for regional areas of bioscience research strength and help to secure targeted funding and research initiatives for UA. Other states are quickly making investments in the biosciences and Arizona cannot afford to be left behind—whether it's funding for technology anchors such as C-Path or its research institutions like the UA.

[19] The *2002 Arizona Bioscience Roadmap* calculated a need for $42 million a year over 8 years (or a total of $336 million) for a Research Enhancement Fund and an additional $10 million a year over 10 years (or $100 million) for research collaborations, consortia, centers, and institutes. These estimates preceded the more detailed analysis by each of the near-term scientific platform committees whose individual and combined reports provide considerable detail on the type, nature, and needs for these investments.

[20] *Platform for Progress: Arizona's Bioscience Roadmap*. Prepared for the Flinn Foundation by Battelle TPP, December 2002, p. 128.

Southern Arizona and UA, to build their research excellence and achieve the commercial economic benefits from it, will need to continue to collaborate with academic medical centers, universities, and other research institutes throughout the state. Arizona cannot excel comprehensively across the board as did places like Boston or San Diego. Arizona and Southern Arizona must focus their research areas, build on strengths, and use collaboration in these focus areas to equal or surpass other centers in the country and the world. Collaboration and specialization go hand-in-hand to positioning Arizona in the biosciences, without creating an impossible goal of excelling in all areas and fields. This collaboration must include linkages to and take advantage of strengths in the biosciences and in fields representing technology convergence, such as optics, engineering, and the natural sciences. Indeed, a number of the region's bioscience firms are located in Southern Arizona because of the strengths of the optics cluster of industry and higher education.

Recent State Investments in the Biosciences

- **Florida's** Scripps investment of $500 million is now being followed with $310 million state/local funds for Burnham Institute to co-locate in bioscience park in Lake Nona; Torrey Pines Institute obtained a $94 million incentive package in Port St. Lucie.
- **Massachusetts** appropriated $120 million for bioscience initiatives including $80 million for a bionano facility at the University of Massachusetts Lowell, bioprocessing and research facilities, matching grant program, and seed fund.
- In **North Carolina**, Dole Food owner David Murdock is trying to transform Kannapolis, NC, into a 350-acre health and nutrition research campus, putting up $1 billion of an estimated $1.5 billion from Dole Food and his development firm; building an initial core lab building and offering $200 million in angel investments—Duke University may run the research facility along with the University of North Carolina System.
- **Washington** State has created a Discovery Fund to support R&D in the biosciences with $350 million received from its share of the tobacco settlement.

Potential Impact:

Regions and states such as San Diego, Maryland, Seattle, San Francisco, and Boston demonstrate the impacts of a strong bioscience research sector aligned with a strong bioscience industry. While such developments do not occur overnight, through steady and ongoing investments states and regions can achieve both national and international research excellence and translate this into newly established firms (start-ups) and commercialization of the research (spin-offs). Tucson and Southern Arizona have already demonstrated their ability to do this. The UA technology transfer office can cite more than 10 start-up bioscience firms that have received its support and assistance during the past 5 years.

Amend Arizona's State Constitution to enable research universities to take equity from licensing in addition to royalties

Rationale:

In 2004, an attempt was made to amend Arizona's State Constitution to enable universities to take equity in addition to royalties when licensing university-developed technologies to industry. Most states west of the Mississippi have similar constitutional provisions, harking back to the turn of the century when state reformers strived to overcome the excesses of the "robber baron" era by strictly limiting state ownership or financial participation in private property. The problem facing public research universities is that licensing a technology may be better achieved by accepting an equity equivalent value rather than a royalty on sales. Being able to do this will require a change in Arizona's constitution. The current focus on royalties does not maximize return to the taxpayers who are financing the state's public research universities. Instead, it encourages licensing technology to an existing firm on another coast or in another country, thus fostering the out-migration of ideas and inventions to other states and nations, and inhibits the ability of university researchers to form local start-up companies. In addition, rapid changes in technology may make a royalty worthless when licensed technology is replaced by newer technology. Everyone loses under the current arrangement.

States such as Utah and Oregon have enacted similar changes in their constitutions in recent years, winning a 60 percent positive vote of the electorate. To increase business and university partnerships, avoid needless administrative confusion, and make Arizona competitive with many other states, a change in the state constitution is necessary. Absent the change, odds are high that Arizona's strong research base will create jobs in other states.

Proposal:

Amend Arizona's constitution to permit university licensing to make equity-equivalent rather than only royalty-type arrangements.

This is an especially important action for UA because it has not formed a limited liability corporation as has ASU. It is also important for encouraging more start-ups. Start-ups are more likely to occur through equity arrangements and also more likely to remain in Southern Arizona, whereas licensing and royalties are more likely to benefit firms located outside Arizona. Because of UA's deep research strengths, along with the entrepreneurial culture nurtured in Southern Arizona, this amendment will be extremely beneficial in turning research into commercial value, with much of it captured in the local Southern Arizona economy.

Potential Impacts:

Amending the state constitution will ease business interactions with UA and contribute toward more flexible equity arrangements that may result in greater financial return to the university and the state's taxpayers. More firms will likely be created in Southern Arizona, and university-business partnerships will increase.

Build a stronger clinical research base to position UA, UMC, and industry in translational research, linking discoveries with patient care and disease treatment and prevention

Rationale:

Increasingly, linkages between basic researchers and clinicians are needed to translate basic research discoveries into patient care and disease treatment and prevention—what some call the linking of bed, bench, and classroom. With the state's Medical College located at UA, its strong College of Sciences focused on interdisciplinary research, and its strengths in bioimaging, asthma, and other areas, Southern Arizona can position itself to increase its clinical trials work with industry, link science and medicine with treatment, and further build the region and the state's translational research capacity.

With the NIH Roadmap for Medical Research[21] emphasizing advancing translational research and re-engineering the clinical research enterprise, it is critical that UA in collaboration with the Southern Arizona VA Medical Center and other regional medical centers, work to ensure a high-quality and effective clinical research environment within Southern Arizona that can be a statewide resource as well. Not only will such an effort help in garnering increased NIH funding, it will ensure that technology commercialization is enhanced to go from bench to bedside.

[21] "Overview of the NIH Roadmap." NIH Roadmap for Medical Research, http://nihroadmap.nih.gov/overview.asp.

Proposal:

The UA Medical College, in conjunction with Tucson and Phoenix hospitals, researchers, and clinicians, needs to build a regional and statewide translational research capacity that demonstrates the benefits of personalized medicine and 21st century medical care.

UA, TGen, ASU, and a number of medical centers recently competed jointly for a planning grant from the NIH to develop a translational research system for the state to advance personalized medicine. The proposal was highly rated and the planning grant awarded. This planning grant, along with work by ABRC/Flinn/Battelle in harmonizing business practices, networking IRBs, and streamlining intellectual property (IP) practices, could position the region and state as leaders in implementing key components of the NIH Roadmap and as the nationally recognized center for translational research**.**

Furthermore, the establishment of C-Path in Tucson, as a collaboration of UA, SRI, and FDA, to assess and develop the approaches to bringing innovative technologies, such as biomarkers, into broader use in the drug approval process, offers a unique resource and platform for propelling Southern Arizona forward in advancing translational research.

Continued emphasis on furthering the clinical research environment at UA is needed. The recent establishment of a cancer clinical center by the Arizona Cancer Center and UMC is such a key step. Additionally, more investment in clinical scholars, dedicated to translational and clinical research, is critical to deepen the talent base needed to move translational and clinical research forward.

Potential Impacts:

This translational work should position the region to be of increased interest to industry undertaking clinical trials and other such work. It should also lead to locating new business opportunities and services in the region and state and further help link UA and its Medical College with other parts of the state.

STRATEGY TWO: CONTINUE TO BUILD A CRITICAL MASS OF BIOSCIENCE FIRMS IN SOUTHERN ARIZONA

Strengthen and expand the region's technology commercialization efforts both at UA and for entrepreneurs outside the university

Rationale:

Most American universities are now staffed with full-time technology transfer offices and associated personnel. However, except for those at medical centers or research universities, this technology transfer work is primarily involved in the passive management of IP and not technology commercialization, defined as creating and growing new technology enterprises.

Increasingly, regions are recognizing the limitations of either turning their research into patents/licenses or forming start-up firms. The overwhelming risk is that the universities will accomplish the innovative research, but the employment and economic impact will occur outside the region. One initial challenge to overcome in the technology commercialization process is to find ways to fund those aspects that create technology from the research, namely:

1. Due diligence, including preliminary market assessments to determine whether the research has value in a product or process. This due diligence can be done by external market or

technology reviewers or by the direct infusion of small amounts of additional funds for application exploration.

2. Pre- and prototype development, which involves creating the process or product needed for patent filings, risk capital financing, or both.
3. Engineering optimization, which involves examining product characteristics versus price and distribution costs.

These are relatively new fields of endeavor for higher education institutions and having funds for them internally is more the exception than the rule. Such funds would help create a competitive advantage for Southern Arizona and would increase the chances that local research and innovation would create local firms and employment.

The UA has shown significant progress in generating spin-offs from its research. Examples of bioscience companies formed around UA research discoveries include Niadyne, ProIX, Melanotan, Amplimed, Cyternex, and Sabino Biosystems. If the university and its researchers had access to funds for due

UA Start-ups, FY 2004–2006

- **Theregen:** UA BIO5 faculty member is Stuart Williams; the company is located in San Francisco, CA. Theregen Corporation (formerly Iken Tissue Therapeutics) is a regenerative medicine company that develops cell-based therapies for patients with cardiovascular and vascular disease.
- **Montigen:** UA BIO5 faculty member is Laurence Hurley; the company is located in Salt Lake City, UT. Montigen uses its drug screening method (CLIMB) to discover and create promising anticancer compounds. Candidate drugs inhibit aurora-A kinase, a gene amplified in most human cancer cells, and small molecules that target tyrosine-kinase receptors that play critical roles in transducing growth signals to cancer cells. Montigen was acquired by SuperGen and no longer exists in name.
- **GUSA**: UA BIO5 faculty member is Mike Hogan, company recently relocated to Tucson, AZ. GUSA technology is based on the low-cost manufacture of DNA microarrays.
- **GenVault:** UA BIO5 faculty member is Mike Hogan; the company is located in Carlsbad, CA. GenVault provides integrated archiving and retrieval solutions for organizations managing DNA collections.
- **Cylene**: UA BIO5 faculty member is Laurence Hurley; the company is located in San Diego, CA. Cylene is developing a first-in-class cancer drug based upon novel structures in DNA that regulate genes. The drug is currently in Phase I clinical trials.
- **RediRipe**: UA BIO5 faculty member is Mark Riley; the company is located in Tucson, AZ. RediRipe is developing an inexpensive produce sticker that changes color when the produce is ripe.
- **Q Therapeutics**: UA BIO5 faculty member is Mani Ramaswami; the company is located in Salt Lake City, UT. Q Therapeutics, Inc., is a biotechnology company founded to develop glial progenitor stem call therapeutics for the treatment and possible cure of glial-mediated diseases in the central nervous system.
- **Queregen:** UA BIO5 faculty member is David Harris, located in Tucson, AZ. The company provides patented expression vectors and services for protein production.
- **Angiomics:** UA BIO5 faculty members are Stuart Williams and Jay Hoying, located in Tucson, AZ. The company has a microvessel model to test new drugs that affect angiogenesis (can be cancer drugs among others). No technology licensed from UA.
- **Topical Technologies:** UA BIO5 faculty member is David Alberts; the company is located in Tucson, AZ. The company was founded to develop new topical agents for the prevention of skin cancer.

diligence, pre- and prototype development, engineering optimization, market and technology assessment, and patent filings, its contributions to building a critical mass of bioscience firms in the region would be even stronger. Ten firms were created in the past three fiscal years based on technologies developed at UA; five of these firms are located in Tucson, the other five are located in either California or Utah.

Proposal:

Establish a Southern Arizona/State Translational Research and Technology Commercialization Fund, managed in concert with the State's higher education institutions.

Institutions including the Massachusetts Institute of Technology, Purdue, and the University of Southern California have received funding support from alumni to create such vehicles or mechanisms. Foundations such as Coulter, Whitaker, and the Mann Institute have also pursued, to varying degrees, similar approaches. Table 14 lists examples of commercialization funds.

Southern Arizona needs to have in place tools for technology commercialization. It is critical to keep these resources together in one fund and not distribute components or specific service elements among different entities.

Table 14: Examples of Commercialization Funds

Institution	Maximum
Boston University "Ignition Awards"	$50,000
Georgia Research Alliance Research Innovation Fund	$100,000
Kentucky Commercialization Fund	$225,000
Maryland University Technology Development Fund	$50,000
Michigan Universities Commercialization Initiative: Challenge Fund	$150,000
Oregon Health and Science University Innovation and Seed Fund	$250,000
Purdue University Trask Funds	$100,000
Rutgers University Technology Commercialization Fund	$20,000
University of Toronto Ideas to Innovation Fund	$125,000
University of Utah Technology Commercialization Project	$70,000

The size of this fund ideally should be $500,000 to $1 million a year; but, the program could start on a smaller basis and be ramped up to a higher level of funding. Because of limited staff and resources today, the UA technology transfer office could use these funds, in conjunction with a community-based entrepreneurship mentoring organization, to expand its staff services as well as to engage external consultants to provide these services and support. **Those states and regions that have developed the capacity to identify market opportunity, have built a research infrastructure, and house the**

Michigan Universities Commercialization Initiative

The Michigan Universities Commercialization Initiative (MUCI) is funded by the Michigan Economic Development Corporation. MUCI was recently extended into its sixth year. Through a Michigan Economic Development Corporation grant stewarded by the University of Michigan, MUCI provides a commonly managed pool for precommercialization research on technologies emerging from every research university in the state and the Van Andel Institute. Awards of up to $150,000 are available, managed by the respective technology transfer office and matched by institutional resources. Supported activities include proof-of-concept research, animal trials, prototype testing, scale-up studies, business plan preparation, and market research. Patenting expenses are not eligible, although institutions may credit their expenditure for patents as a partial match to a MUCI award. Institutions must repay three times the grant received by assigning 20 percent of any licensing income consequent to a MUCI project. The program was funded at $2 million for 5 years. In 2005, a repayment of $20,000 was made from its first successful project.

resources necessary to support technology commercialization are much better positioned to turn knowledge and innovation into economic development for their state and locality.

Potential Impact:

A Translational Research and Technology Commercialization Fund would give Southern Arizona a strong tool to assess, review, evaluate, and form the base of new firms. But, having premiere research underway in a state or region does not guarantee that its applications will also occur there. As many regions have discovered, locally created innovation and research can easily migrate to other states and regions. Having funds to do due diligence, pre- and prototype development, and engineering optimization will increase the value of licenses, and, in conjunction with the earlier action regarding changing the state's constitution to enable universities to take equity, could result in more spin-off bioscience firms in Southern Arizona.

Increase awareness of and access to specialized facilities and laboratories at UA

Rationale:

National surveys of the bioscience industry undertaken by Battelle and others have found that firms are particularly interested in interacting with universities to gain access to specialized laboratories and facilities and associated use of equipment. And, such initial relationships often lead to sponsored research and other relationships in the future.

Proposal:

Continue and expand UA's efforts to increase its efforts to publicize and make industry aware of its laboratories, facilities, and equipment, and otherwise make it easier for the region's and state's bioscience industry to access them.

UA has a unique and strong asset in ARL, which is apparently as likely today to be used by out-of-state universities and firms as those in the state. Protocols, agreements, and user arrangements have been established and efforts should be undertaken to communicate this asset to the region's and state's bioscience industry. In addition, access to other university assets should be reviewed and determinations made as to the terms and conditions for accessing these assets, such as the successful industry partnerships in use of animal facilities. Priority must be given to faculty and students and, if federal funding was involved in the financing of the asset, its terms and conditions must be taken into account as well. Subject to such concerns, ways to make this information Web-based and more accessible would be an effective first step in increasing communications and

Workforce + Facility = Competitive Advantage

The new Biomanufacturing Training and Education Center (BTEC) on North Carolina State University's Centennial Campus is the largest facility of its kind in the nation and helps answer the state's need for biomanufacturing training. BTEC will simulate a biomanufacturing pilot plant facility capable of producing biopharmaceutical products and packaging them in a sterile environment. It also will include support training and educational classrooms, laboratories, and building and process utilities. Students will gain experience using the same equipment they would use on the job. The center also will help attract new biomanufacturing companies to North Carolina; assist the development of new technologies for production of value-added biopharmaceuticals, protein-based products and chemicals from organisms, plants, cell cultures, and other biobased systems; and enhance the creation of rural biomanufacturing jobs and new agribusiness opportunities.

partnering. Over time, the university may want to consider additional facilities and equipment for its purposes and of interest to the region's bioscience industry. Examples of this strategy are the pilot Good Manufacturing Practices facilities and similar pilot-scale plants created by North Carolina State University across a range of its colleges.

Potential Impacts:

Access to specialized laboratories, equipment, and facilities is an effective way to build stronger university-industry partnerships in the region. Increasing awareness of such assets and how to access them can lead to other partnerships and relationships. For smaller firms that cannot afford expensive or unique equipment or facilities, this access could prove critical to the firm's growth and survival.

Increase industry partnerships with UA, C-Path, and other research institutions in the state through matching grants, industry fellows, clinical trials, and other approaches

Rationale:

Industry seeks two things from universities: an educated workforce and scientific discovery and ideas that have commercial potential. Much of the educated workforce serves as the primary bench scientists for research discovery. Industry in Southern Arizona and elsewhere finds it challenging to determine where and how to enter a university, make connections, and build relationships. An R&D voucher or matching grant program could encourage greater industry-university interactions. Such a program could be piloted in Southern Arizona, given its existing bioscience industry base.

Proposal:

Southern Arizona should secure state funding for an R&D Voucher Pilot Program, to be used to increase connections and linkages of UA and industry.

First established and designed in Kentucky, the concept has now spread to Georgia, North Carolina, and Puerto Rico. While a voucher program can be designed in many different ways, the preferred approach, to minimize administrative costs and time delays, might include the following:

1. A process of application, review, and approval is established to obtain a voucher on a centralized basis through a designated agency (local or state).
2. The application criteria for award include the following:
    a. Equal matching funds dedicated to the proposed project by the applicant (industry)
    b. Focus of project within the identified bioscience technology platforms
    c. Identified faculty members/university affiliation (alternatively, the voucher could be given to the firm and the firm given the opportunity to find a matching university partner/faculty member)
    d. Joint signatures from authorizing representatives of industry and university partners
    e. Commitment to design, development, and production of products in the region or state with penalty provisions if not achieved.

This program is designed to ensure that industry is driving the project and that the project is of commercial interest to the firm. The university partner, on the other hand, has mutual veto power over whether it wishes to participate to ensure academic relevance and avoid "job shop" projects.

Potential Impact:

The R&D voucher initiative provides another way for Southern Arizona to work with the state in linking its strong set of local bioscience entrepreneurs with UA and other universities in the state. This can lead to other ongoing relationships and allows emerging talent from the university working on a funded project to work with cutting-edge firms. Partnerships such as this can lead to employment opportunities and result in retaining more of the region's talent.

Continue to build and invest in C-Path as an additional technology anchor for industry linkages to the region

Rationale:

Battelle's 2006 national report for BIO[22] identified as one national trend efforts of states and regions to establish "technology anchors"—entities that are between industry and higher education and marry the best of both worlds as collaborating mechanisms. TGen in Phoenix represents an earlier version of this phenomenon; C-Path represents the second-generation anchor. Both these anchors will likely become pivotal to the state's future efforts to build its bioscience research and industry base. State and philanthropic sources may need to invest in these types of entities until they reach sufficient scale with leveraged outside dollars and no longer need this interim support.

Proposal:

Provide financial and community support to secure the long-term survival and growth of C-Path as an important technology anchor for the region's and state's bioscience future.

C-Path has secured initial funding and is engaging the drug and pharmaceutical industry in unprecedented collaborations. To maintain its neutrality, C-Path must be careful about the types of funds it accepts and the functions and roles it performs. It is important that the state and region recognize C-Path as the next best thing to Arizona's own federal laboratory. Consequently, general funding support from the community and state will likely be required for C-Path to reach its full potential.

Potential Impacts:

C-Path can attract the drug and pharmaceutical industry to the region as well as other nonprofit entities such as SRI. It can also help to establish the region's and state's reputation as an effective university-industry collaborator, putting the region and state on the bioscience roadmap of the nation and the world. C-Path's growth and evolution could conceivably move toward that of a national laboratory over 10 to 20 years.

STRATEGY THREE: BUILD A TALENT BASE THAT CAPTURES AND RETAINS SOUTHERN ARIZONA'S HUMAN RESOURCES

An increasingly discriminating variable for regions is likely to be their talent pool. Recent studies and reports point out that where graduate or undergraduate students decide to live and work after graduation may be a key variable for a region's intellectual climate and talent competitiveness, as are the number of Endowed Scholars. Fortunately, Southern Arizona is in a position to attract both graduates and faculty—

[22] *Growing the Nation's Bioscience Sector: State Bioscience Initiatives, 2006*. Prepared for BIO by Battelle TPP and SSTI, April 2006. The full report can be accessed online at http://www.bio.org/local/battelle2006/.

the short-term challenge is that the region's employment structure cannot accommodate all UA graduates who would remain in the region if suitable employment were available, according to many of Battelle's interviewees.

As Southern Arizona builds a critical mass of bioscience firms, and as business service providers staff up with individuals knowledgeable of biosciences to service these firms, job opportunities should increase. These graduates cover a range of colleges within UA, from master's of business administration students to those in pharmacy, agricultural sciences, engineering, and medicine. Furthermore, a more sophisticated approach to regional economic development can offer the talent pool of the region as a comparative advantage for firms considering moving to or expanding in the region, as several bioscience firms have already done.

Finally, a key long-term concern is to encourage more students in elementary and secondary education to be interested in science, math, engineering, and technology while still in school. This issue needs to be addressed not only for outstanding students, but for minority, low-income, and disadvantaged students as well. To position Southern Arizona as a bioscience talent center able to meet the workforce needs of existing, new, and attracted firms, two talent career paths must be created. The first focuses on the need for "serial entrepreneurs," individuals who have been through the trials of start-up successes and failures. Secondly, career pathways in the biosciences must be created for all students in elementary and secondary education and beyond.

Form an executive-in-residence program to increase the supply of readily available serial entrepreneurial talent to support and place in newly formed bioscience enterprises

Rationale:

Emerging clusters of bioscience industry face challenges in finding sufficient entrepreneurial managers—CEOs, chief financial officers (CFOs), chief operating officers (COOs), and senior regulatory and marketing staff—to start, grow, and develop bioscience firms. In many regions of the country, sufficient experienced entrepreneurs (those who have successfully launched several firms) are hard to find. This shortage occurs in those regions that lack a track record and/or a critical mass of firms. Consequently, the size of the existing entrepreneurial pool is very limited. Various regions such as Pittsburgh, St. Louis, and, more recently, Cincinnati, have undertaken or are proposing to undertake an "executive corps" or "entrepreneur-in-residence" program to attract and locate in their regions such serial entrepreneurs from around the country (Table 15). These serial entrepreneurs are recruited with the understanding that they will be located in a firm in need of their skills and

Table 15: Examples of Entrepreneur-in-Residence Programs

Institution	Location
Calgary Technologies, Inc.	Calgary, Alberta
Drexel University Biomedical Entrepreneurship Program	Philadelphia, PA
Duke Institute for Genome Sciences and Policy	Durham, NC
Georgia Institute of Technology, Advanced Technology Development Center	Atlanta, GA
Girvan Institute of Technology	Santa Clara, CA
Illinois Ventures	Chicago, IL
Kentucky Technology Enterprise Corporation	Kansas City, KS
Life Sciences Greenhouse	Pittsburgh, PA
Research Triangle Institute (RTI)	Research Triangle, NC
Sandia Federal Labs	Albuquerque, NM
University of Illinois Technology Entrepreneur Center	Urbana-Champaign, IL
University of Texas College of Engineering	Austin, TX

experience within 18 months of their arrival. In the meantime, they can mentor or coach a number of bioscience start-ups and/or manage with others a regional pre-seed/seed fund to invest in bioscience start-ups. Lack of sufficient serial entrepreneurs is a serious problem in most of the emerging bioscience centers across the country. One emerging bioscience region recently reported that more than one-third of its bioscience CEOs were commuting weekly. Such a situation does not bode well for growing a firm or ensuring that it will remain in the region.

Proposal:

Form an entrepreneur-in-residence program in Southern Arizona to "bank" serial entrepreneurial managers as coaches/mentors until placed in managerial responsibility within a bioscience enterprise.

The interesting variation for Southern Arizona and other parts of Arizona is to take advantage of a unique asset—the senior managers from the drugs and pharmaceuticals; medical devices; and research, testing, and medical laboratories industries who are retiring to Southern Arizona. While some have become engaged in mentoring and coaching, these retirees represent an untapped resource to help bioscience entrepreneurs build their businesses. They remain untapped because start-ups lack knowledge of their availability, ways to engage them easily, and the financial resources perceived as necessary to secure such assistance.

This effort should be initiated with three to four such entrepreneurs in residence at any one time to maintain focus and ensure quality and results. The duration of assignment is expected to vary; but, because many of the entrepreneurs will already reside in Southern Arizona, they may be willing to take on "spot" assignments, thus serving as a more permanent cadre of entrepreneurs in residence. It is projected that two or three of the four would be of this type, with one or two moving permanently into a particular firm within 3 to 18 months after becoming an entrepreneur in residence. Efforts to find such entrepreneurs should focus on individuals who have an entrepreneurial bent; have experience in the key industry segments in which firms are forming in Southern Arizona—research, testing, and medical laboratories and medical devices and equipment—and have recently been active in their industries so to be up to date on competitiveness issues.

For organization and management of this program, these entrepreneurs in residence could be located at the McGuire Entrepreneurship Program in the Eller College of Management at UA. McGuire already has a mentor-in-residence program to serve all industry sectors, and its students are active in support of the Office of Technology Transfer at UA. The McGuire program and the Eller College are ranked among the top entrepreneurship programs in the country in many national surveys.

Potential Impact:

An entrepreneur-in-residence program, providing the counsel and guidance of experienced serial entrepreneurial managers, can have a significant impact on the rate of new bioscience enterprises being created and surviving. This should help move Southern Arizona more quickly to a critical mass of bioscience firms.

Expand career pathway opportunities for students to pursue careers in the biosciences

Rationale:

It is becoming increasing difficult for bioscience firms throughout the country to meet all their employment needs within their region. If this issue is not resolved, regions may improve their ability to start new firms, but will be unable to retain them (and their subsequent employment growth) because of a lack of technician-level employees. This shortage is already seen in the hospital community. In recent years, community colleges have established new programs, such as Pima Community College's Science Careers in the 21st Century. This program, funded for 2 years by the U.S. Department of Labor, is designed to interest high school students in science careers. The students investigate various scientific career options by participating in field trips, interacting with scientists, and conducting hand-on projects. They learn how to research a career, develop an education plan, and set career preparation goals. At the high school level, specialized Bioscience Academies are being created around the country; and the Tucson Unified School District is considering a similar approach. Finally, because of rapid changes in technology, it is essential for the bioscience workforce to be educated on a lifelong basis—which necessitates the building of career ladders whereby high school graduates can enter and exit with various skill levels, moving from technician to postdoc or scientist if he or she should desire at some point in his or her career. Because of its strong quality of life and the interest of its young people in obtaining good, well-paying jobs, Southern Arizona should offer such career pathways to obtain support of the region for the growth of the bioscience sector while maintaining careers for the children and grandchildren of the region's residents.

Salt Lake Community College Biotechnology Program

The Biotechnology Technicians Program is a 2-year A.A.S. program in which students master skills required for technical positions in biotechnology research and manufacturing. The program emphasizes partnerships with local industries to provide students with the most current and cutting-edge knowledge and techniques in the field. It provides hands-on experience with over 100 hours spent in the laboratory, beginning in the second semester. Skills include DNA cloning and analysis, expression and purification of proteins, cell culture techniques, enzyme and antibody assays, bioprocessing, bioinformatics, industrial standards, and communication skills. Students will do internships at local biotechnology companies, giving them a unique opportunity to apply their knowledge in an industrial environment. Courses are taught by faculty with extensive experience in laboratory research.

Shorewood High School Biotechnology Program, Shoreline, WA

This year-long course is designed for students with an interest in genetics, microbiology, immunology, and molecular biology. It allows students to explore topics such as polymerase chain reaction, gene sequencing, genetic engineering, transformation, and various other techniques currently used by scientists in the workplace. Classroom experiences include participation in the Human Genome Project, independent research, visits to laboratories, guest speakers, career readiness activities, student leadership involvement, and ethical discussions. In addition, students enrolled in the Biotechnology course at Shorewood High School can earn occupational credit through either Shorewood or the Northeast Vocational Area Cooperative, a consortium of eight cooperating high schools in the Seattle area. Skills required for the course include a strong science background in biology and chemistry, good analytical skills, and attention to detail.

Proposal:

Several interrelated issues need to be addressed in building career pathways for encouraging students to pursue careers in the biosciences:

1. **Form a Bioscience Academy for high school students**
2. **Address part of career education (K-12) to encourage bioscience programs for 11th and 12th graders.** The proposed FY 2008 budget for Arizona Career and Technical Education includes as a top priority funding for biomedical, health, genomics, technologies, and science, as well as for engineering and math.
3. **Continue to expand Pima Community College's technical programs and transfer programs in the biosciences (histology, medical technician, etc.)**
4. **Address articulation between Pima Community College and UA for science and technical majors to achieve bachelor's and advanced degrees**

This four-part effort ensures that not only the most gifted students are addressed through the Bioscience Academy, but that those from all income groups and backgrounds can be included through a tech-prep-type 11th- and 12th-grade bioscience program articulated with Pima Community College bioscience programs. These, in turn, need to be linked to upper division programs at UA as well as graduate programs.

The goal of these four components is to ensure lifelong learning and education so that young people can see opportunities at the high school, community college, 4-year college, and graduate school levels; leave at any point; and re-enter again as desired. The region thus will build a career path for a stronger bioscience workforce in the future.

Potential Impact:

Creating, retaining, and ensuring lifelong education opportunities for bioscience workers will position the region as a center of talent to attract and grow the bioscience industry. By beginning at the high school level, through both the Academy and career education, early interest of students can be encouraged and developed by providing opportunities at the community college, undergraduate, graduate, and post-graduate levels.

STRATEGY FOUR: ADDRESS AND MAINTAIN A BUSINESS CLIMATE SUPPORTIVE OF THE BIOSCIENCES AND THEIR GROWTH IN SOUTHERN ARIZONA

Address shortage of risk capital for the biosciences in the region and state through a BioSeed Fund, angel funds, and recruiting of out-of-state risk investors

Rationale:

Risk capital is a complicated subject. Its nomenclature can be confusing as to market gaps, the focus of formal venture capitalists, the stages of investment, and the activities of programs and organizations. The problem is confounded in the biosciences because the business model for some segments requires considerable resources and long time periods to go through clinical trials and obtain FDA approvals.

Since the dot-com bust of 2000 and 2001, all regions of the United States have seen a precipitous drop-off in equity financing for technology start-ups in general and the biosciences specifically. Since 2004, bioscience investments have increased generally in 2005; investments in bioscience firms exceeded those in IT in Arizona for the first time. However, Arizona currently receives very small amounts of venture fund investments. Only $119 million of venture capital was invested in Southern Arizona bioscience firms in the past 10 years (1996 through the third quarter of 2006), with $54 million of the total being invested in one firm, ImaRx. The focus of the investments in Southern Arizona firms in recent years has moved from health services to biopharmaceuticals, while the medical devices and equipment subsector has stayed fairly steady as an investment target (Table 16 and Figure 14).

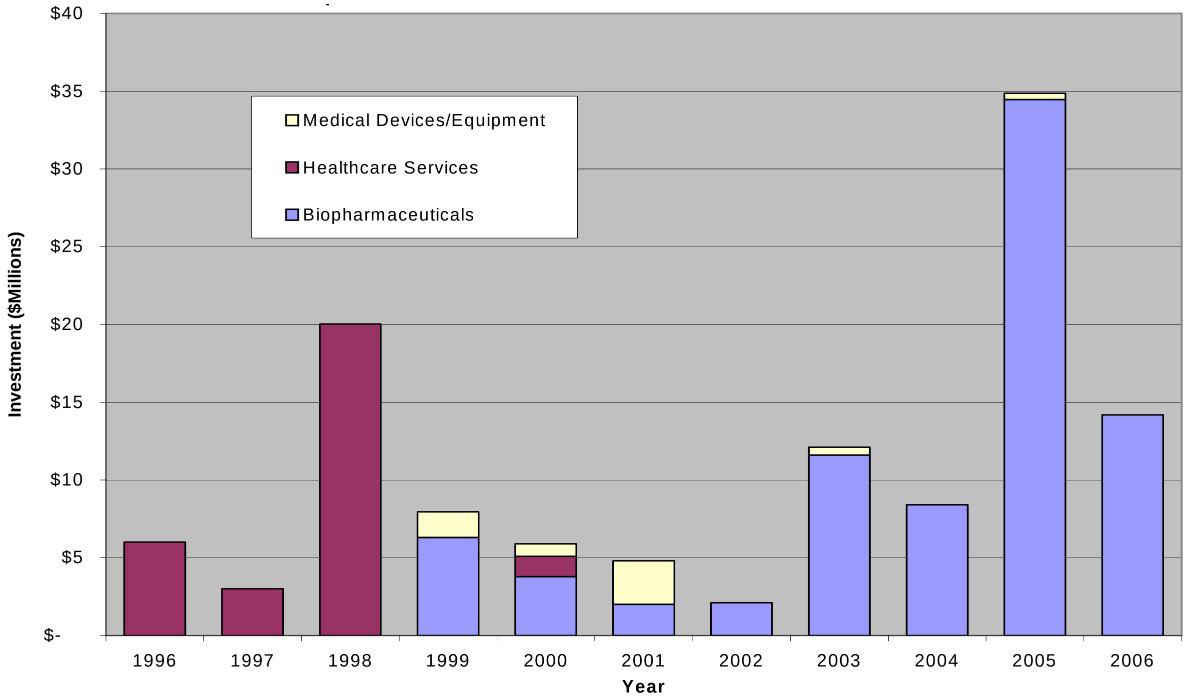
Table 16: Venture Capital Investments in Southern Arizona Bioscience Firms, 1996–Q3 2006

Venture Capital Investments in Southern Arizona Bioscience Companies (1996 - Q3, 2006)				
Sector	**Company**	**# of VC Deals**	**Year(s) Investments Occurred**	**Total Investment ($Millions)**
Biopharmaceuticals	AmpliMed	2	2003, 2005	$ 15.7
	High Throughput Genomics	4	2002, 2004, 2005	$ 6.1
	ImaRx Therapeutics	8	1999, 2001, 2002, 2003, 2004, 2005, 2006	$ 54.3
	Niadyne	3	2000, 2005	$ 6.2
	Sedecim Therapeutics	1	2000	$ 0.6
	Sector Total	**18**		**$ 82.8**
Healthcare Services	MatureWell	3	1996, 1998	$ 25.5
	Providence Service	3	1997, 1998, 2000	$ 4.8
	Sector Total	**6**		**$ 30.3**
Medical Devices/Equipment	CytoDome	2	2003, 2005	$ 0.9
	Harmonia Medical Technologies	5	1999, 2000, 2001	$ 5.3
	Sector Total	**7**		**$ 6.2**
Southern Arizona Total for the Biosciences		**31**		**$ 119.3**

Source: Battelle analysis of Thomson Venture Xpert database.

Historically, Southern Arizona, relative to the rest of Arizona, has had a strong set of venture firms and investors, including Solstice, Valley Venture, and Coronado. Tucson is headquarters to RCT, the now-independent technology commercialization engine, formerly associated with Research Corporation of America. (However, none of these three venture anchors has formed new funds recently and their existing funds are generally depleted except for some dollars reserved to maintain existing relationships.) In addition, individuals associated with out-of-state funds located in the region may, from time to time, make investments. Finally, several Southern Arizona–based firms have sought and succeeded in obtaining East Coast and West Coast venture dollars.

Figure 14: Venture Capital Investments in Southern Arizona Bioscience Firms, 1996–Q3 2006



Source: Battelle analysis of Thomson Venture Xpert database.

In general, the conclusion of those interviewed is that local equity dollars are limited at almost all stages—from initial investments of $250,000 to several million and all formal venture capital stages. Given the lack of IPOs nationally in the biosciences in 2006, small, young bioscience firms without alternative revenue streams are having difficulties, making it necessary for them to enter into strategic alliances with drug and pharmaceutical firms or operate on extremely limited resources far below those needed to get a product to market.

Southern Arizona needs risk capital both prior to stages where formal venture capital managers are interested and at levels exceeding $2 million. The *Arizona Bioscience Roadmap*[23] recommended forming an Arizona BioSeed Fund as a statewide entity with sufficient resources to address the pre-venture capital range of investments, usually $250,000 to $2 million. It was recommended that this fund have up to $70 million available, not all at the pre-seed or seed stage, and be administered by the same entity handling technology commercialization. This action proposed making Arizona home to a venture capital community committed to early-stage local investment. This is one of a handful of actions in the Roadmap that has not yet been implemented. The experiences of Maryland, Pennsylvania, Michigan, Wisconsin, and other states working to address their capital gaps for the biosciences suggest the following:

- There are varying degrees of success or failure in forming bioscience-focused pre-seed and seed funds.
- Funds have been developed both regionally and statewide.
- The single largest obstacle to creating these funds is finding sources of capital to finance them.

[23] *Platform for Progress: Arizona's Bioscience Roadmap*. Prepared for the Flinn Foundation by Battelle TPP. December 2002.

- Many of these efforts have multiple objectives: (l) to build a venture capital industry where a state or region is the home for such funds, regardless of where their investments are made; and (2) to encourage more investments in the private sector market gaps, usually in the $250,000 to $2 million range, within that state or region.

Proposal:

Continue to advocate for a statewide Arizona BioSeed Fund with upwards of $50 million to $75 million available for bioscience investments. In lieu of such a statewide fund, consider establishing a Southern Arizona Bioscience Fund with $25 million or more available for pre-seed investments.

In the 2005 legislative session, Arizona did pass an investment tax credit to encourage early-stage investments in smaller enterprises, with an additional tax credit given for the biosciences. The state has issued rules and regulations for the program, representing one approach to encouraging angel investors to support the development of bioscience firms. But, this credit will not address all investment stages for bioscience firms; a BioSeed fund also will be needed. To help fill this capital gap, approaches might include the following:

- Encourage private and public pension funds to invest.
- Encourage the pooling of funds by the philanthropic community to serve as a match to encourage formal venture capitalists to come the state and region.
- Encourage experienced bioindustry retirees and other wealthy private individuals to invest in an Arizona BioSeed Fund.

Potential Impact:

A deep research base and a strong entrepreneurial culture—both hallmarks of Southern Arizona—are important for the region to fully participate in the bioscience revolution. But, equally important are sources of capital to grow bioscience firms in Southern Arizona. Bioscience entrepreneurs in the region cite difficulty convincing out-of-state investors that there is “bio” in the region on which to build. A lack of deep local anchor investors further discourages out-of-state investments in regional start-ups unless investors require firms to locate where they are located. Addressing this private sector capital gap is absolutely critical if the region is to have a critical mass of firms and IP of UA is to be turned into local firms, rather than licensed anywhere in the country. As stated earlier, unless this issue is resolved, the fruits of Southern Arizona’s strong research base will out-migrate, drawn by the resources necessary to start and grow emerging firms.

Address space needs of bioscience firms through combination of incubator and accelerator space and development of a bioscience-focused research park

Rationale:

A region has begun to achieve a critical mass of bioscience firms when more and more bioscience entrepreneurs report difficulty in finding space. While Southern Arizona has not reached that point yet, as it continues to grow its industry, it will need good-quality dry- and wet-lab and office space for start-ups and for firms in their second and third rounds of expansion. Firms need water, air, filtration, and other safety and health infrastructure in their location sites. Such leasehold improvements are expensive, and developers are often unwilling to build or outfit such space if they are unconvinced of a succession of bioscience tenants.

The current UA Research Park offers some wet-lab and office space for start-ups. But, its location is not ideal because it is removed from town and from UA researchers who collaborate with such early-stage firms. The proposal to establish a Bioscience Park at Kno and 36th Street, while subject to some discussion and disagreement, conceptually helps address the need for incubator and accelerator space for bioscience firms on a larger scale than provided by the current UA Research Park. Regardless of specific zoning or other impediments to this site, it is clear that Southern Arizona needs to support and assist the development of a bioscience research park if it wants to participate in the BioCentury. Other regions throughout the country—from South Lake Union in Seattle, to Mission Bay in San Francisco, to the University of California in San Diego—are devoting strong support to such a concept. A core physical presence and site for bioscience firms to congregate is essential to the growth of this cluster in Southern Arizona.

Proposed Tucson Bioscience Park

Characteristics:
- Close to university and medical center
- Will facilitate the connection of research and industry
- Will offer flexible space for bioscience firms as they evolve and grow with smart shell design, dry and wet labs, office and administration functions

Attributes:
- Mixed-use campus
- Association with a university
- Potential for expansion
- Open space

Elements:
- Science research laboratories
- Office buildings
- Technical high school
- Hotel and conference center
- Open space

Proposal:

Establish a bioscience research park close to UA to address bioscience firms' needs for space from start-up to expansion.

Southern Arizona needs to offer a location close to UA for bioscience firms to form, develop, and grow. Biomedical research parks are a growing international phenomenon, and Southern Arizona needs to find ways to link the increasing and often unique space needs of its bioscience industry with efforts to address community redevelopment. It is too risky for the private sector to respond to bioscience space needs; that will come only after the market is much more developed and mature. UA, with nearby incubation and accelerator space, can encourage spin-offs and start-ups from its research faculty.

Potential Impact:

A physical site for collocation has been shown in other parts of the country to be a key factor in growing a critical mass of bioscience firms. Incubator and accelerator space is important to bioscience entrepreneurs because of the long lead time from discovery to product introduction and the need for expensive systems such as air, water, and other infrastructure. Private sector developers in Southern Arizona and throughout the state and country lack interest in building such space.

Ensure that the region's and state's tax and regulatory approaches are supportive and conducive to the growth of bioscience firms

Rationale:

While special or additional tax incentives may not be necessary for bioscience firms to succeed, regions and states must ensure equal and fair treatment of these firms relative to their traditional or historic industry base, generally favored by regulations and tax policies. Bioscience firms usually desire equitable, stable, and predictable tax and regulatory policies. Existing tax structures and regulatory regimes that greatly impact the biosciences include hazardous materials, fire marshal regulations, zoning and planning controls, and polices toward sales and use tax for materials not yet resulting in a finished product.

Proposal:

Undertake a systematic review of the region's and state's tax and regulatory policies as they affect growing bioscience firms in Southern Arizona.

While interviewees generally were not aware of specific regulatory or tax policies adverse to their growth and development, it was clear that this issue has not been thoroughly reviewed. One concern was expressed that the personal property tax on equipment was penalizing bioscience firms in Arizona. A systematic review can identify other issues and problems that can be addressed appropriately at each level.

Potential Impact:

Ensuring that the region and state are treating bioscience firms fairly and not putting them at a competitive disadvantage means that firms can relocate to, start, or grow in the region. A review can help determine whether there are any impediments to this objective.

Develop strategic targets of opportunity in the biosciences for recruitment of firms and focus economic development efforts on such targets

Rationale:

In terms of regional economic development, studies suggest that most bioscience firms begin where their entrepreneurial founders are located. But, firms can move for various reasons such as acquisitions and mergers and collocation with their venture financiers. The larger medical device, drug and pharmaceutical, and bio ag firms increasingly are looking to build strategic alliances with small, young, growing firms wherever they are located. This represents an opportunity to attract satellite operations, whether R&D or manufacturing, to such locations. For economic developers, it is important that they ascertain their strategic assets and target their bioscience recruitment efforts accordingly.

Proposal:

Focus Southern Arizona's economic development recruiting around the following strategic assets or opportunities:

- The Technology Platforms on which UA's expertise and knowledge are based (as described earlier in this report)
- Technology convergence strengths of the region to link strengths in optics, ag biotech, and other areas with bioscience firm interests
- Joint ventures between drug and pharmaceutical and medical device industries for R&D and applications development in Southern Arizona, with sister state alliances with Mexican provinces where product manufacturing can occur with assembly and packaging on the U.S. side
- Identify those firms using specialized labs and facilities in the region such as the Large Animal Facilities at UA or RCT in Tucson.

In addition to these specific factors, general selling points to attract biosciences to the region should include the region's talent pool, its legacy of bioscience role model successes, and access and partnering opportunities with UA.

Potential Impact:

Recruiting around the region's assets and opportunities is a more effective way to attract targeted bioscience firms to the region. However, most of the economic impact of the biosciences will involve establishing entrepreneurs and encouraging their growth—this will far outweigh the impact of firms recruited to the region.

Address other business and quality-of-life issues affecting bioscience firms and their workers

Rationale:

Increasingly, the major asset of bioscience firms is their workforce. Quality-of-life attributes are important factors in attracting and retaining such a workforce. Southern Arizona offers an extremely high quality of life, and efforts should be made to maintain it in order to grow the bioscience industry.

Proposal:

Address key quality-of-life issues of concern to bioscience firms and their employees including

- **Ease access to Phoenix through I-10 improvements, air connections, and video and Internet meetings; and**
- **Continue to enjoy a good climate, pleasant pace of life, smooth traffic flow, and lower cost of living.**

While some of these factors are changing as the region grows, such as traffic congestion, Tucson still proves to be competitive relative to other urban areas. A similar case can be made in regard to cost of living, which, while rising, is competitive in the Southwest and with California.

Potential Impact:

Increasingly, employees move to where they would like to work and then find a job. Southern Arizona offers an outstanding quality of life and is a destination desired by high tech, including the biosciences, workers, and their families. Addressing those problems that deter from such quality-of-life issues is an effective role for local government and economic development groups. It will help ensure that the region can attract and retain the talent it needs to further grow its bioscience base.

Fund staffing for BIOSA so it can offer expanded networking and other functions as well as serve as an effective advocate for the biosciences in Southern Arizona and a partner with ABA statewide

Rationale:

Bioscience firms tend to mingle with other bioscience firms, interact with related businesses, connect with university personnel, and otherwise engage in what is termed "technical networking." This is much more the case than in industries such as IT and manufacturing, which tend to view their colleagues as competitors rather than potential collaborators. Bioscience firms realize that they have many different niches in which to operate, enabling many complementary efforts among them.

Proposal:

Fund staffing for BIOSA so it can offer expanded networking and other functions as well as serve as an effective advocate for the biosciences in Southern Arizona and a partner with the Arizona BioIndustry Association statewide.

In Battelle's 2006 report for BIO,[24] 42 states were identified as having a statewide bioscience association; some states also have counterpart regional associations. There are effective ways for statewide and regional associations to work together on common problems and target respectively state or regional needs. Strong support exists within Southern Arizona for strengthening BIOSA; its biggest challenge is to find resources to fund full-time staff. Specific additional roles BIOSA needs to focus on, as ascertained by Battelle's interviews, include the following:

1. **Expanding network opportunities**, e.g., business to business and industry to researchers. Networks can focus around industry segments, around common positions in each firm, e.g., CFOs, CEOs, COOs, Human Resources, Regulatory, etc. There is a strong interest in more networking opportunities for firms, including increased knowledge and awareness of firms, university resources, and business service support.
2. **Building capacity of service providers in the biosciences**. The region can't have sufficient expertise within its business service providers if there is not enough local work to keep them busy. Even today, a great deal of legal, IP, and accounting work leaves the region. BIOSA needs to increase efforts to involve business service providers and encourage their development of greater expertise in the biosciences.
3. **Expanding Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) support and assistance.** While some successful firms have taken advantage of the federal SBIR/STTR programs in Southern Arizona, more assistance and support needs to be provided to increase the success rate of the region's entrepreneurs.
4. **Expanding efforts to serve as the regional advocate for the bioscience industry and statewide work closely with ABA.** It is critical that the bioscience industry have a stronger voice in public policy affecting the industry**.**

Potential Impact:

A strong trade association can help encourage connections, communications, and championing of the industry. As demonstrated in regions as diverse as San Diego and Maryland, such associations play a significant role in building a brand and image and contribute to the building of a critical mass of firms, supportive public policy, and linkages among and between sectors. The lack of funding for staffing BIOSA not only prevents the region from leveraging and growing its current bioscience assets, but can give outsiders the impression that the region is not serious about growing this sector.

[24] *Growing the Nation's Bioscience Sector: State Bioscience Initiatives, 2006*. Prepared for BIO by Battelle TPP and SSTI, April 2006. The full report can be accessed online at http://www.bio.org/local/battelle2006/.

STRATEGY FIVE: EDUCATE, INFORM, AND SPUR TO ACTION OPINION LEADERS AND THE GENERAL PUBLIC ON SOUTHERN ARIZONA'S FUTURE IN THE BIOSCIENCES

Build champions/local leadership within industry, the public sector, and higher education to implement this Southern Arizona Bioscience Roadmap

Rationale:

Regions that have diversified their economies into the biosciences or other technologies have found one factor essential to success: engaging the region's civic leadership behind the roadmap. Building champions across the industry, university, and government sectors is critical to success**.** Champions are those persons respected by their peers who have the stature, time, and commitment to help mobilize resources for the future. In some communities, this may be one person—such as Dr. William Danforth, Chancellor Emeritus at Washington University in St. Louis—but, in most regions, it involves several champions from industry, government, and the civic sector—such as the Robert W. Woodruff Foundation; Dwayne Acker, Chairman of BellSouth; other utility executives; and the heads of Emory University and Georgia Tech who served as champions for their respective segments in Georgia.

Proposal:

Identify and anoint champions to implement this Bioscience Roadmap for Southern Arizona.

Responsibilities for implementing this Roadmap must be assigned to various public, civic, education, and industry leaders. The SALC has already identified many of these champions, in terms of the officers and members of the Steering Committee guiding the development of this report. Furthermore, Steering Committee leaders are already heavily involved and taking leadership roles in two important statewide bioscience implementation vehicles—the Bioscience Steering Committee, under the auspices of the Flinn Foundation; and Science Foundation Arizona, recently established to invest and support the state's research and educational efforts in the biosciences and related science and engineering fields.

The next section describes the priorities among the many strategy actions, the time frame for initiation, and the organizational and structural issues and agents needed for successful implementation. Southern Arizona champions must help refine these plans, mobilize resources behind them, and monitor the progress of the region in the implementation of this Roadmap, making adjustments as the marketplace changes and as dramatic breakthroughs continue in the science and technology of the biosciences.

Potential Impact:

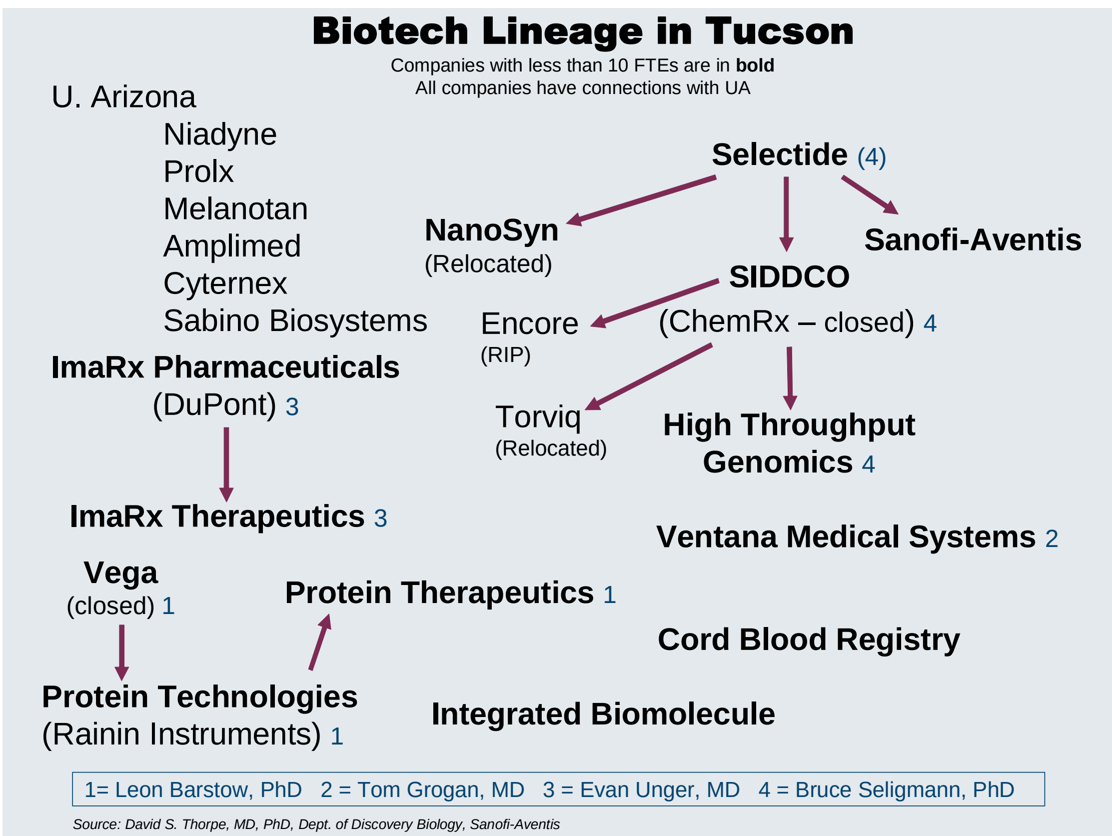
A successful Roadmap implementation effort must involve key leaders and the understanding that recognizes progress is long term, not short term. However, momentum can be created and maintained through short-term successes. Champion leadership for the process should recognize short-term successes within the long-term approach. Champions are critical to the mobilization of resources across all sectors and toward building a harmony of purpose and a commitment toward working together.

Celebrate role models and entrepreneurial and firm successes as part of a regional and statewide public education and awareness effort in conjunction with the statewide brand (Biozona) within and outside the state

Rationale:

Southern Arizona has a number of successful bioscience firms and entrepreneurs. Figure 15 shows a genealogy tree of such firms and the importance of such individuals as Leon Barstow, Tom Grogan, Evan Unger, and Bruce Seligmann. These individuals exemplify “serial entrepreneurs” but are largely unsung heroes in the region, state, and nation. In some ways, it is Southern Arizona’s best-kept secret—the birthing of a series of bioscience firms whose founders move on to create a chain of such interrelated firms—something more often associated with Silicon Valley, Boston, and San Diego, rather than Southern Arizona or Arizona. Southern Arizona excels not only in serial entrepreneurs, but also in creating and growing bioscience enterprises.

Figure 15: Genealogy of Bioscience Companies in Southern Arizona



Interestingly, at the ABA Awards dinner on June 1 of this year, Southern Arizona captured a large percentage of the awards, including the following:

1. AmpliMed Corporation, as Arizona’s Bioscience Company of the Year
2. DMetrix, as Bioscience Start-Up Company of the Year
3. Ventana Medical Systems, as Medical Device Company of the Year.

Indeed, Southern Arizona captured four of the five company awards that evening. This demonstrates not only the base of firms, existing and new, established in Southern Arizona, but their strength statewide in leading the state's bio revolution.

Proposal:

Celebrate role models and entrepreneurial and firm successes of Southern Arizona as part of a regional and statewide public education and awareness effort in conjunction with the statewide brand (Biozona) both within and outside the state.

Success begets success as demonstrated in regions such as Maryland, San Diego, and Research Triangle. A low-cost, effective approach to both building momentum around the biosciences and encouraging others to become bioscience entrepreneurs is to identify, cite, and celebrate successful bioscience serial entrepreneurs and successful bioscience enterprises. Clearly, since the *Arizona Bioscience Roadmap* was released in December 2002, the statewide printed media has done an outstanding job of focusing on the biosciences, including the researchers, firms, and products. But, general citizen awareness of bioscience entrepreneurs, who they are, what they do, and what they have accomplished, has not yet been created in Southern Arizona or elsewhere in the state. The existing mass of such entrepreneurs is in Southern Arizona, and both regional and statewide organizations need to focus on these role models because they can and will spur others to also start or join bioscience enterprises in the region and state. Research stars who drive research discovery and build Arizona's bioscience research excellence have generally been given more attention, particularly in the Phoenix area. These role models need to speak to public officials, opinion leaders, general business leaders, and civic leaders in Southern Arizona and statewide.

Potential Impact:

Increased public awareness as well as civic leadership awareness of these successes and role models adds a human touch to what some might perceive as rather exotic work. Real people in Southern Arizona are making a difference in the biosciences; and putting faces to these efforts helps everyone to identify with, own, and support efforts to further build a bioscience-driven economy in the region.

Implementation Plan

INTRODUCTION

The previous sections of this Southern Arizona Bioscience Roadmap assessed where the region stands today in terms of its bioscience economic base, its talent base, and its capital base; identified its core competencies and technology platforms from a rigorous quantitative and qualitative analysis of both university/medical center and industry data; identified key drivers and assets upon which to build a stronger bioscience-driven regional economy over the coming decade; and concluded with a set of five strategies and 17 actions to guide public and private investment in future years. This section of the report lays out the major actions critical to success, the immediate priorities, the organization and structure for moving this Roadmap forward, the resources required, and accountability measures of success on which to measure and judge progress.

The actions described in this Roadmap, while requiring some public catalytic action in the initial stages, rely, for the most part, on the private and philanthropic sectors, federal funding sources, and others to achieve significant progress and impact. In many cases, the effort is focused on ensuring that the private sector market gaps are addressed and filled over the long-term by private actions and private investments, such as addressing the need for risk capital, developing a bioscience research park, and increasing technical networking among firms and universities.

Wherever possible, existing entities' roles and responsibilities should be expanded to implement these activities. The preference should be to reconstitute or use existing organizations and programs whenever possible in the implementation of this Roadmap. Stakeholders should be encouraged to use this approach where it makes sense in terms of efficiency, but equally important, in terms of achieving results.

CRITICAL ACTIONS

The successful implementation of the following nine of the 17 actions in this Roadmap will determine whether the region can be competitive in as a bioscience center:

1. Build champions/local leadership to implement the Southern Arizona Bioscience Roadmap within industry, public sector, and higher education
2. Establish technology commercialization support to build a critical mass of bioscience firms
3. Build an executive-in-residence program for increasing supply of entrepreneurial managers
4. Strengthen BIOSA
5. Form statewide and/or regional BioSeed Fund
6. Offer sufficient incubator and accelerator facilities including bioscience research park
7. Continue to build and invest in C-Path as additional anchor
8. Amend state constitution to permit universities to take equity from licensing
9. Secure additional state, federal, and private resources to fully utilize facilities and further build research strengths

Immediate Work Plan Priorities

Immediate work plan priorities are those steps the private and public sectors in Southern Arizona should undertake in the first 12 months of implementation. Several critical priorities need to be implemented right away, while others will need to be planned and resources secured before they can move forward.

The following actions should be undertaken in the first year of Roadmap implementation:

- Identify champions and assign responsibility for Southern Arizona Bioscience Roadmap implementation
- Work with Science Foundation Arizona and state to secure their support in implementation of this Roadmap including funding for the following:
    - Research excellence—universities and technology anchors
    - Technology commercialization
    - Executives in residence
    - R&D pilot voucher program
- Complete work under NIH Clinical and Translational Science Award (CTSA) planning grant to seek full funding to further build capacity regionally and statewide
- Develop communications and education plan for the biosciences in Southern Arizona including role model success stories
- Move forward with bioscience park and incubator/accelerator space
- Monitor and assess C-Path progress and needs
- Complete planning for Biosciences Academy
- Assist in establishment of statewide BioSeed Fund
- Determine time frame for state constitutional amendment with Bioscience Steering Committee.

Resource Requirements

Table 17 illustrates the priority of each action and the annual and one-time costs. Overall, these costs total $272 million over 10 years in annual and one-time funding (although all programs are not initiated at the same time, as noted in the “Time Frame” column), including private, government, and other sources. One-time costs are estimated to total $71 million. Public and philanthropic costs total $117 million, and private funds total at least $155 million and probably much more as the bioscience research park is developed.

Table 17: Activity Time Frame and Financial Requirements

Activity	Time Frame	Financial Requirement	
		Annual	One-time
Secure additional state, federal, and private resources to fully utilize facilities, secure and retain entrepreneurial faculty, and further build the UA's research excellence	Short Term	Statewide: $100 million/year	
Amend Arizona's State Constitution to enable research universities to take equity	Short Term		$500,000 education campaign
Build a stronger clinical research base	Mid-Term	Secure $10 million federal and additional industry funds	
Strengthen and expand the region's technology commercialization efforts	Short Term	$1 million/year	
Increase awareness of and access to specialized facilities and laboratories at UA	Immediate	Costs paid by business users	
Increase industry partnerships with UA, C-Path, and other research institutions in the state through matching grants, industry fellows, clinical trials, and other approaches	Short Term	$500,000 R&D voucher pilot program	
Continue to build and invest in C-Path	Short to Mid Term	To be determined	
Form an executive-in-residence program	Short Term	$500,000 to $625,000/year	
Expand career pathway opportunities for students to pursue bioscience careers	Mid-Term	To be determined	
Address shortage of risk capital for biosciences through a BioSeed Fund, angel funds, and recruiting out-of-state risk investors	Short Term		Statewide $70 million fund
Address space needs through incubator and accelerator space and bioscience-focused research park	Short Term	$15 million to $100 million private and public funds dependent on size and phasing	
Ensure region's and state's tax and regulatory approaches are supportive	Mid-Term		$250,000 study
Develop strategic targets of opportunity in the biosciences for recruitment	Mid-Term	Use existing economic development funds	
Address other business issues affecting quality of life	Short Term	$50,000 to $100,000	

Table 17: Activity Time Frame and Financial Requirements (continued)

Activity	Time Frame	Financial Requirement	
		Annual	One-time
Establish a fully staffed BIOSA	Immediate	$50,000 to $100,000 annually	
Build champions/local leadership to implement Roadmap	Immediate	Time	
Celebrate role models and entrepreneurial and firm successes	Immediate	Existing resources	

ORGANIZATION AND STRUCTURE

This Roadmap proposes a set of strategies and actions that involve many private and public sector organizations.

There are four primary components to the organization and structure for the Southern Arizona Bioscience Roadmap to move forward in implementation:

1. Create a stronger industry-driven BIOSA organization. BIOSA shall serve primarily as a trade association for the industry and its partners in higher education, government, and the civic and philanthropic communities. Specific actions were suggested earlier as the primary domain of BIOSA and moving its agenda forward:
   - **Expanding network opportunities**, e.g., business to business and researcher to researcher. There is a strong interest in more networking opportunities for firms, including increased knowledge and awareness of firms, university resources, and business service support.
   - **Building capacity of service providers in the biosciences**. BIOSA can ensure its "associate" members are involved, are drawn upon by industry for their assistance, and encouraged to build further their knowledge and services to the biosciences. Today, a significant amount of legal, IP, and accounting work leaves the region. BIOSA needs to involve business service providers and encourage their development of greater expertise in the biosciences.
   - **Expandeding SBIR/STTR support and assistance.** More assistance and support can be provided to increase the success rate of the region's entrepreneurs. While a severe shortage of pre-seed and seed capital in the region may adversely impact the start-up and growth of firms, SBIR/STTR represents an alternative way to secure funding. States such as Massachusetts, Maryland, and California have used these federal programs effectively in lieu of private risk capital funds to build their bioscience industries.
   - **Expanding efforts to serve as the regional advocate for the bioscience industry and statewide work closely with ABA.** It is critical that the bioscience industry have a stronger voice in public policy affecting the industry.
2. Place responsibility for undertaking the interrelated issues of technology commercialization (market and technology assessments, due diligence, pre- to prototype development, engineering optimization) and business planning support services in one entity. In previous work for both Pittsburgh and St. Louis, Battelle suggested that one organization undertake these interrelated

responsibilities. In both instances, local leaders decided to split these functions among multiple groups with several results: (l) tendency in using risk capital funds for later non-seed stage investments; (2) limited linkages to university technology transfer offices; and (3) an over-emphasis on investing dollars and an underinvestment in due diligence/technology assessment work. Three options are proposed for Southern Arizona:

a. Option One: Locate these functions in the Technology Transfer Office at UA and expand its functions into technology commercialization. Currently, the office undertakes some technology commercialization functions on a case-by-case basis; recently, it had difficulty finding $12,000 for some due diligence work. Giving the office functions and responsibilities in technology commercialization along with the resources identified previously would help address a major current gap.

b. Option Two: Locate these functions with responsibilities for the research park and economic development at UA, which will link these functions to ease offering support to entrepreneurs outside the university.

c. Option Three: Locate these functions over the long term with BIOSA, once it has the resources to hire staff. For BIOSA, these functions would be additional to SBIR, networking, and advocacy functions.

3. Complete work under NIH CTSA planning grant to seek full funding to further build capacity regionally and statewide.

4. Continue the existing Steering Committee as is or in a reconstituted fashion, or use the SALC Board as the key organization responsible for monitoring progress in implementation of this Bioscience Roadmap. As part of this task, key champions should be identified and made responsible for each of the five strategies.

The SALC Board and its staff can serve as the organizers, advocates, and agenda setters in the short term. This avoids the need to create any additional formal organizations, which should resonate well with business and government leaders in the region. It provides specific roles for BIOSA to undertake and perform, and the key challenge will be to raise resources to move forward with the first-year work program items listed previously.

Measures of Success and Accountability

Unlike traditional roadmaps or strategies, the strategies laid out in this Roadmap actually provide specific measures that can be monitored to determine the progress and impact of Roadmap implementation. The following should be used to track progress in implementing the Roadmap:

- **Jobs and Firms.** Grow the technology firms in the region to increase specialization to at least equal to the nation in one industry segment by 2011 and two segments by 2016.
- **Risk Capital.** Increase total bioscience investments in the region to $100 million by 2011.
- **Research Base.** For the 5-year period through 2011, gain $33 million in inflation-adjusted funding to bring UA life science research funding to $288 million. By 2016, reach top 20 overall and top 10 among public universities by gaining $66 million in inflation-adjusted funding from 2004 amount to bring the UA life science research funding to $321 million.

- **Commercialization of University Technologies.** Increase commercialization success of the region's universities as measured by start-ups, licenses, equity returns, and sales of IP to exceed the top quartile of all universities by 2016.
- **Overall Progress.** Show progress in implementing 75 percent of the 17 actions in 3 years and substantial progress in implementing 90 percent of the actions in 5 years

In addition to these impact measures, the region should consider updating this Roadmap every 3 to 5 years to adjust to changing economic and market conditions.

CONCLUSION

Southern Arizona represents Arizona's bioscience entrepreneurship center. It has a strong track record of start-ups succeeding start-ups in a robust genealogical tree; UA has a strong track record of bioscience spin-offs from its research; and both the university and industry are making plans to build further research excellence in their core competencies and achieve a critical mass of bioscience firms in the region. This Roadmap charts a set of strategies and actions for implementation over the next 5 years, identifies priorities and a time frame for each action, and identifies the resources required for the action to move forward. Measures of success are proposed, as is an organizational design and structure to oversee monitoring and implementation of this Roadmap.

Appendix A:

Southern Arizona Bioscience Steering Committee

University of Arizona

Leslie Tolbert, Vice President for Research
Bruce Wright, Associate Vice President for Economic Development
Eugene Sander, Dean, College of Agriculture and Life Sciences
Keith Joiner, Dean, College of Medicine
Lyle Bootman, Dean, College of Pharmacy
Joaquin Ruiz, Dean, College of Science
Vicki Chandler, Director, BIO 5
David Alberts, Director Cancer Center
Paul Portney, Eller College of Management

Pima Community College

Ann Christensen, Division Dean Instruction—Mathematics, Science & Technology

School Districts

Roger Pfeuffer, Superintendent, Tucson Unified School District

Affiliate Research Organizations

Norm Botsford, CEO, University Physicians, Inc.
Greg Pivirotto, CEO, University Medical Center
Ray Woosley, President and CEO, C-Path Institute

Institutional Organizations

Saundra Johnson, Vice President, Flinn Foundation
Dr Edward Spack, Senion Director of PharmaSTART and Biosciences Business Development SRI International
Michael Cusanovich, President, BIO SA
Joe Snell, President & CEO, TREO
Jim Gentile, President, Research Corporation
Jeff Trent, President, T Gen
Steve Lynn, Southern Arizona Leadership Council
Sandra Watson, Governor's Innovation and Technology Council
Bob Hagen, Southern Arizona Technology Council

Private Sector

Chris Gleeson, CEO, Ventana Medical
Evan Unger, CEO, ImaRx
Loren Acker, CEO, SEBRA
Jack Dean, Vice President for Research and Development, Sanofi-Aventis
David Thorpe, Principal Scientist, Dept of Discovery Biology, Sanofi-Aventis
Robert Green, President, Integrated Biomolecule
Bruce Seligman, President, High Throughput Genomics
Robert Ashley, President & CEO, AmpliMed
Frank Maloney, Chief Business Officer, Acenta Discovery
Felix Munoz, Client Executive, IBM
Dr Scott Leischow, Arizona Cancer Center, Dep Dir of Strategic Partnerships
Rick Gibson, Clear Blue Ventures
Rick Krivel, Alliance Bank of Arizona
Roger Vogel, SEBRA
Mel Cohen, Mesch, Clark & Rothchild, P.C
Jannie Cox, Carondelet Foundation
Joe Coyle, Ratheon Missile Systems
John Bremond, KB Home Tucson, Inc

SALC

Rick Myers, IBM Executive (retired), SALC Chairman
Ron Shoopman, President, SALC

Appendix B:

Southern Arizona Biosciences
Core Competency Assessment

Universities are the national leaders in basic and applied bioscience research and it is extremely important that bioscience-based economic development strategies be constructed on a firm base of understanding of the capabilities of a state's research universities and associated institutes. Research universities are likewise at the forefront of developing and adopting enabling technologies for advancing bioscience R&D and it is important to understand the availability and investment in these tools and resources (such as imaging, instrumentation, advanced materials, combinatorial chemistry resources, etc.) since they make such a strong contribution to development pathways. It should also be noted that university core competencies can serve as a magnet for the attraction of commercial research linked to the universities' expertise and specialized focus areas—helping to build a localized environment conducive to specialized bioscience business development and growth.

The biosciences present so many opportunities for the future (Table B1) that it is extremely important for a state or region to have a strong basis of understanding of where its opportunities will lie within a very broad universe of bioscience disciplines, opportunity areas and possibilities. An extremely small number of states (most notably California and Massachusetts) have such a broad academic and industry base in biosciences that they may be able to build on strengths across the board, but in most technologically savvy states (such as Arizona) opportunities will present themselves in more tightly defined fields and the state must be ready to support and help build capabilities in identified specialized niches.

It is the identification of these niche areas of opportunity, built around an understanding of Southern Arizona's bioscience core competencies that are the focus of this report. This core competency focuses primarily on the University of Arizona in Tucson, but also considers other non-profit research drivers such as the Southern Arizona Veteran's Administration Hospital and the Critical Path Institute. It also is informed by earlier work Battelle conducted in developing the Arizona Biosciences Roadmap in 2002 and advancing the Scientific Platforms in cancer research, bioengineering, bioimaging and neurosciences in more recent years. At the same time as this analysis was conducted, Battelle has been conducting an update of the overall core research competencies found in Arizona, and parts of that analysis—particularly the cluster analysis of overall research grants are incorporated in terms of the results for University of Arizona.

Table B1: Potential Bioscience Breakthrough Areas

Human Biosciences	Plant Biosciences	Animal Biosciences
• The prevention of diseases with underlying genetic causes • The development of early stage disease diagnostics • The ability to detect genetic predisposition to disease and develop prevention and treatment regimens • The production of advanced imaging technologies to promote new discovery and enhance therapeutic delivery • The discovery and development of new drugs and biologics for enhanced treatment outcomes • Drugs and therapies targeted to individual genomic characteristics leading to greatly improved outcomes and reduced side-effects • The development of replacement tissue and organ systems to replace those injured or failing • The biological integration of advanced technologies, such as nanotechnology, biomaterials and MEMS devices • Advanced bioinformatics and health informatics tools to drive knowledge-based medicine. • The ability to eradicate, inoculate against and more effectively treat established and emerging infectious diseases • Enhanced biosecurity	• Pest and disease resistant crops • Increased crop yield and desirable qualities characteristics • Lengthened growing seasons via cold resistance or reduced light requirements • Enhanced shape, texture, flavor and processability characteristics • Technologies to reduce the required application of fungicides, herbicides and insecticides • Functional foods and nutraceuticals • Plant genetic resources for development of biologics, drugs and pharmaceuticals • Genetic resource (germplasm) preservation and storage technologies • Development of biosensors for industrial and commercial applications • "Biopharming" and the production of novel and useful chemicals via plant pathways • Development of sustainable bio-based fuels • Development of advanced biomaterials for use in construction and other industrial applications • Development of degradable plastics from plant starch, protein and fermentation-produced monomers • Bioremediation and environmental protection via plants • Enhanced biosecurity	• New approaches to animal disease diagnostics, prevention and treatment • Increased food animal meat yield and desirable quality characteristics • Improved technologies for food preservation and the prevention of spoilage and food-borne diseases • Genetic resources for development of biologics, drugs and pharmaceuticals for human and veterinary applications • Xenotransplantation and tissue engineering, providing organs and tissue for human medical applications via animal pathways • Development of engineered species, such as customized predator insects, to control pests and diseases • Development of biosensors for industrial and commercial applications • Bioremediation and environmental protection via microbial pathways • The use of animal waste and byproducts as renewable energy and chemical production resources • Enhanced biosecurity • The novel application of animal and plant genetic resources to new technologies such as biological computing

The potential for discovery and innovation in the broad areas of opportunity shown in Table B1 is tremendous. Multiple forms of economic development may take place around such bioscience opportunity areas, including but not limited to the following:

- The formation, growth and attraction of companies engaged in
  - Drug development and manufacturing
  - Biologics development and manufacturing
  - Vaccine production
  - Gene therapy development
  - Diagnostic test development and production
  - Diagnostics and imaging instrumentation manufacturing and development
  - Laboratory and diagnostics services and healthcare services
  - Medical implants and invasive devices
  - Tissue engineering and organ systems development
  - Seed and plant varietal development and production
  - Improved food animal species and enhanced animal health
  - Agricultural and food processing technologies
  - Biomaterials and biocomposites development
  - Biofuels and bio-sourced chemicals
  - Production of novel and useful compounds via plant pathways
  - Agricultural equipment and precision agriculture devices
  - Bioinformatics and health informatics tools and software
  - Biosecurity
  - Waste management and environmental clean-up and protection
  - Nanotechnology and MEMS devices
  - Other bio and bio-related commercial applications yet to be developed or imagined.
- The diversification of existing commodity producers, such as farms, into enhanced value-added products.
- Direct economic benefits from research itself, brought by the attraction of external research funds and the scientists and staff they support.
- Enhanced education and workforce development in and around biosciences and technology.
- Increased health, wellbeing and human capital capacity generated through healthcare and wellness innovations, clinical care and healthcare products.

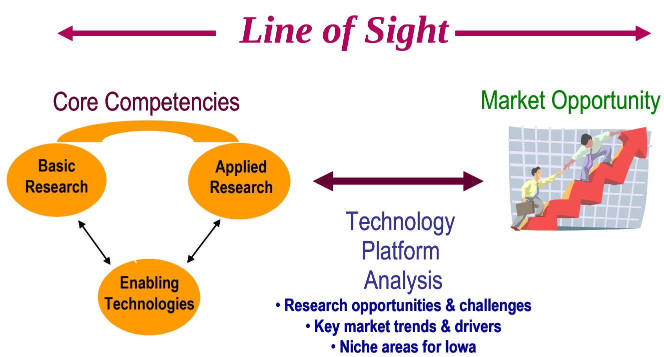
Because research is the driving force behind bioscience innovation and commercialization—and therefore, the driving force behind the realization of the potential economic development opportunities highlighted above—it is imperative that Southern Arizona's decisions regarding science and technology policy for advancing the biosciences be constructed upon a formal understanding of the state's bioscience research core competencies.

As noted previously, a core competency analysis for the state was conducted in 2002—but for this report Battelle has performed a new in-depth assessment and evaluation of the Southern Arizona region's bioscience core competencies and resulting technology platforms. This analysis will allow stakeholders in Southern Arizona to see where previously identified competencies have been retained and strengthened, where new competencies are emerging, and where further investments may be required to achieve the desired level of strength and capabilities.

METHODOLOGICAL APPROACH TO ASSESSING SOUTHERN ARIZONA'S CORE RESEARCH COMPETENCIES

Underpinning the successful translation of bioscience research strengths into economic development opportunities requires recognition of the importance of "market-driven" processes. The traditional model of commercialization assumes a "research-driven" approach to commercialization. This research-driven commercialization process proceeds in a pipeline fashion from basic research leading to a major scientific breakthrough, to applied research leading to product development, and ending with industrial manufacturing and marketing. The shortcomings of the research-driven approach are that it is too divorced from commercialization and product development needs and has uncertain economic value. The market-driven approach recognizes that commercialization is a highly interactive process involving close ties between research activities and business development activities. Success depends, as the Council on Competitiveness points out, "on a team effort that includes carefully focused research, design for manufacturing, attention to quality and continuous market feedback."[25]

Figure B1: Line of Sight



As seen in Figure B1, the components of a core competency area can bring together basic research, enabling technology, and applied research activities with a "line of sight" that moves seamlessly to address clinical needs and market opportunities, and can form robust technology platforms. Core competency areas that lack this linkage and connection to needs and market opportunities offer more limited development opportunities.

Defining Core Competencies

There is no one single source of information that serves to identify core research competencies and focus areas. Rather, a variety of integrated and complementary analyses are required to help identify an institution's current position and areas of focus that may lead or contribute to Southern Arizona's future bioscience growth.

[25] Council on Competitiveness, *Picking Up the Pace: The Commercial Challenge to American Innovation* (Washington, DC: Council on Competitiveness), pp. 9-10.

In identifying core research focus areas in the biosciences, Battelle's objective was to identify those fields where there is an ongoing critical mass of activity along with some measure of excellence. This does not mean, however, that other fields of bioscience excellence may not be present within Southern Arizona institutions. What it does mean is that these other bioscience strengths are found in relatively limited pockets and so offer more limited opportunities upon which to build (but they may still contribute in a notable manner).

To take the analysis further, Battelle applies an industrially focused core competency definition that is widely used by technology-based firms. As defined by Hamel and Prahalad, in "Competing for the Future,"[26] a competence is a bundle of skills and technologies, rather than a single discrete skill or technology. It represents the sum of learning across individual skill sets and individual organizational units.

Three tests can be used to identify a core competency:

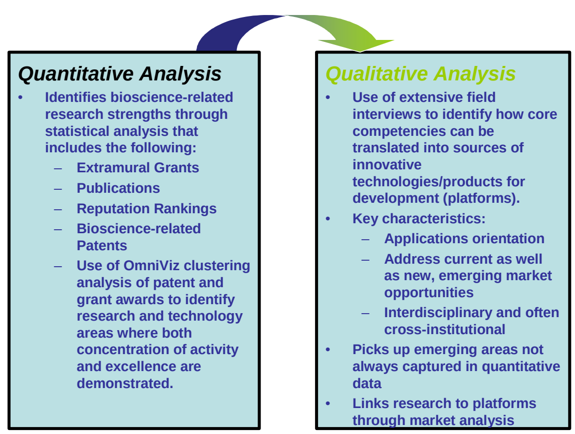
1. Is it a significant source of competitive differentiation? Does it provide a unique signature for the state?
2. Does it transcend a single business? Does it cover a range of businesses, both current and new?
3. Is it hard for competitors to imitate?

Approach to Identifying Southern Arizona's Bioscience Research Core Competencies

Core research focus areas are identified using both quantitative and qualitative methods (Figure B2):

- Quantitative assessment uses statistical information on extramural grants, publications, and patent activities—as well as application of the Battelle- developed *OmniViz™* software tool to identify research clusters—to develop an understanding of the trends and characteristics of bioscience research within Southern Arizona institutions.
- Qualitative work includes extensive field-work interviews with key administrators, scientists, and researchers across the research drivers found in Southern Arizona organizations and institutions.

Figure B2: Quantitative/Qualitative Analysis



The questions that the research team explored in the core competency assessment focused on the following:

- What is Southern Arizona's overall volume of bioscience research and what trends, positive or negative, are being demonstrated?
- In which fields of bioscience and related activities are Southern Arizona R&D institutions receiving significant levels of funding, especially funding from "gold standard" sources such as the National

[26] Hamel, G. and Prahalad, C. K. 1994. Competing for the Future. Harvard Business School Press: Boston, MA.

Institutes of Health (NIH), the U.S. Department of Agriculture (USDA), National Science Foundation (NSF), etc.?

- In what bioscience and related fields do Southern Arizona academic institutions demonstrate a substantive and influential record of publication?
- In which bioscience areas is the University of Arizona generating patents and intellectual property?
- Which areas of bioscience and related fields does the University of Arizona self-identify as core competencies?
- Based on identified core competencies, what development opportunities can be identified for the near-term (over the next five years) for growing the biosciences and related industries and technologies in Southern Arizona?
- Which bioscience core competencies show the most promise for becoming growth poles for incorporation into Southern Arizona's statewide technology and economic development policy?
- Which core areas of bioscience focus require additional investment in Southern Arizona in order to realize their development potential?

In evaluating the answers to these questions, the team can provide insights into the current strengths of the Southern Arizona biosciences research base and draw implications as to how these research strengths may best intersect with the state's industry and economic base, economic competitiveness factors, and market trends to produce economic opportunity. Ultimately the goal of the core competency assessment is to identify significant strengths that form a substantial signature for the state around which substantial bioscience-driven economic development can occur.

Quantitative Assessment of the Southern Arizona Bioscience Base: Identification of Potential Core Competency Areas

In this section we examine the specific areas of bioscience and bioscience-related activities in Southern Arizona that receive extramural funding. The volume of funding and numbers of investigators are used to indicate the most active bioscience fields in Southern Arizona's research institutions, of which the University of Arizona in Tucson is the primary organization. NIH, USDA, and NSF data are used for this analysis.

The ISI citations database—a source providing detail on research "output" in terms of number of papers published, by discipline, and the average number of citations received per paper—is also used. ISI maintains a detailed database of U.S. scientific papers and associated citations, allowing Arizona's academic paper output in biosciences and related disciplines to be compared with national norms and indexed for relative impact. ISI data also allows for the calculation of the relative concentration of individual bioscience fields within institutions against national norms.

These statistical sources were used to derive an overview of research core competencies and to give a more specific description of the bioscience expertise within Southern Arizona research institutions. An area is identified as a core competency area when it has the following:

- A significant number of bioscience-related research grants awarded through rigorous peer-review processes such as those at the NSF, USDA and NIH
- A broad base of principal investigators, along with prominent biomedical researchers who hold multiple peer-review grants
- A substantial level and impact of publications.

Research Core Competency Areas Suggested by Federal Funding Data

Federal R&D Funding Obligations and University Expenditures

A summary of the federal funding obligations for R&D to the University of Arizona in 2003, the most current year for which these data are available, reveals that the majority of research is funded by awards from the Department of Health and Human Services—nearly $105M out of $190M, or 55%. Because this department is home to the NIH, this points to a strong research emphasis at the U of A on health-related and biomedical sciences (Table B2). NSF is the second largest source of R&D funds to the university, with $41.4M in 2005; NASA is the third largest source, with $17.1M.

Table B2: Federal Funding Obligations for R&D to the University of Arizona, 2003 ($ thousands)

Federal Funding Source	R&D Funding
All Agencies	**190,027**
Departments	
Department of Agriculture	7,207
Department of Commerce	1,488
Department of Defense	9,317
Department of Education	304
Department of Energy	5,010
Department of Health and Human Services	104,843
Department of Housing and Urban Development	0
Department of the Interior	2,827
Department of Labor	0
Department of State	0
Department of Transportation	35
Other Agencies	
Agency for International Development	0
Appalachian Regional Commission	0
Bureau of Engraving and Printing	0
Environmental Protection Agency	467
General Services Administration	0
National Aeronautics and Space Administration	17,133
National Science Foundation	41,396
Nuclear Regulatory Commission	0
Office of Justice Programs	0
Social Security Administration	0

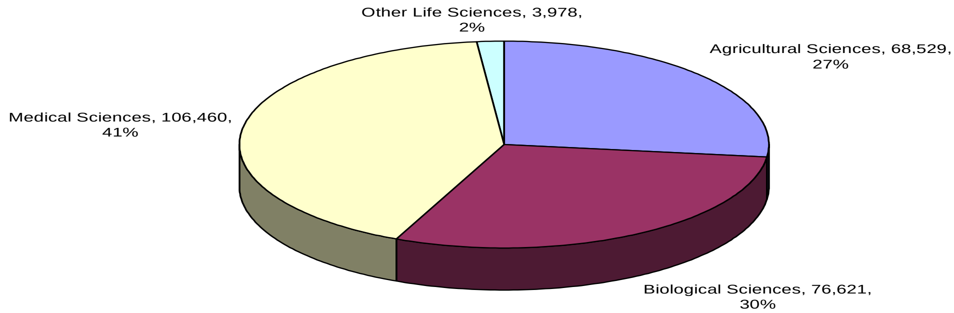
The degree to which these funds are directed towards biosciences may be inferred from Table B3, which shows the distribution of R&D expenditures across research disciplines in 2004. By far, the discipline where most expenditure was made was Life Sciences, at $255.6M. $124.6M of R&D expenditures was in the Physical Sciences, most of which went to Astronomy; $53.5M of expenditures were in Engineering Sciences, directed largely towards Electrical Engineering and Mechanical Engineering.

Table B3: Academic R&D Expenditures by Science and Engineering Discipline at the University of Arizona, 2004 ($ thousands)

Discipline	R&D Expenditures
Engineering Sciences	53,542
Aeronautical and Astronautical	2,898
Bioengineering/Biomedical Engineering	2,321
Chemical Engineering	5,235
Civil Engineering	9,412
Electrical Engineering	15,978
Mechanical Engineering	13,813
Metallurgical and Materials Engineering	597
Other Engineering	3,288
Physical Sciences	124,566
Astronomy	108,671
Chemistry	11,312
Physics	4,583
Other Physical Sciences	0
Environmental Sciences	11,971
Atmospheric	3,001
Earth Sciences	8,970
Oceanography	0
Other Environmental Sciences	0
Mathematical Sciences	5,060
Computer Sciences	5,585
Life Sciences	255,588
Agricultural Sciences	68,529
Biological Sciences	76,621
Medical Sciences	106,460
Other Life Sciences	3,978
Psychology	4,136
Social Sciences	18,212
Economics	5,699
Political Science	245
Sociology	8,796
Other Social Sciences	3,472
Other Sciences	20
All Disciplines	**478,680**

Within Life Sciences R&D expenditures, Medical Sciences accounted for 41%; Biological Sciences, 30%; and Agricultural Sciences, 27% (Figure B3). The near-equal distribution of each of these three fields suggests that the university has diverse strengths across the biosciences spectrum instead of in just one area.

Figure B3: Distribution of life sciences research funding by sub-fields at the University of Arizona, 2004



Next we examine NIH, USDA and NSF funding at the department level, which suggest specific areas of research strength in Southern Arizona.

NIH Funding

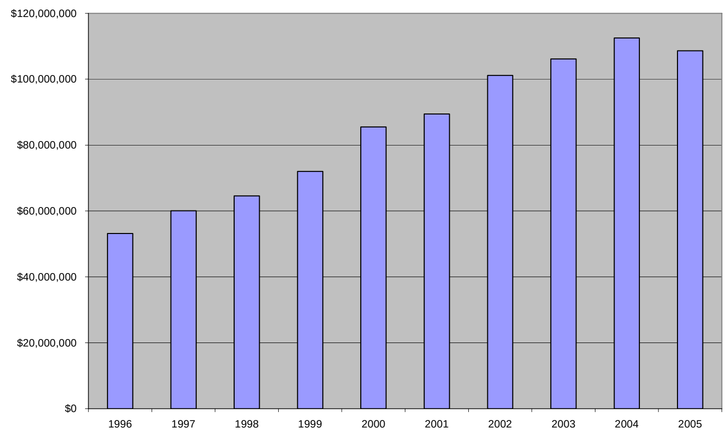
The NIH is generally considered the "gold standard" of funding for biomedical research and basic biological sciences research oriented towards human biology and health sciences. In 2005, NIH awards to Arizona totaled over $175.9 million; of this amount, Southern Arizona captured $115.7M, or 65.7% of all NIH research funds awarded to the state (Table B4). NIH funding within Southern Arizona was divided across 15 institutions or organizations. The University of Arizona received the lion's share of Southern Arizona research funds with $108.6M, accounting for 93.8% of Southern Arizona NIH funding.

Table B4: Southern Arizona Institutions or Organizations Receiving NIH Funding (2005)

Organization	Dollars Awarded	Percent of Southern AZ Dollars
UNIVERSITY OF ARIZONA	108,596,865	93.8%
DMETRIX, INC.	1,446,817	1.3%
PROLX PHARMACEUTICALS CORPORATION	1,234,561	1.1%
ARETE ASSOCIATES	885,259	0.8%
ACENTA DISCOVERY, INC.	711,311	0.6%
IMARX THERAPEUTICS, INC.	618,943	0.5%
MEDICAL DIRECTIONS, INC.	561,500	0.5%
NEOGEN, LLC	349,915	0.3%
NIADYNE, INC.	344,127	0.3%
HIGH THROUGHPUT GENOMICS, INC.	250,000	0.2%
BIOPSY SCIENCES, LLC	233,458	0.2%
PIMA COMMUNITY COLLEGE	203,580	0.2%
SCIENCE-APPROACH	106,892	0.1%
HYDRO GEO CHEM, INC.	100,000	0.1%
WESTERN RESEARCH COMPANY, INC.	100,000	0.1%
	115,743,228	**100.0%**

The University of Arizona is clearly the human biomedical research and associated basic biological sciences research leader in Southern Arizona. From 1996 to 2005, NIH total award funding to the University of Arizona increased from $53.2M to $108.6 M and by an average of 8.4% per year (Table B5). The University of Arizona consistently ranked between 48th and 54th nationwide amongst institutions receiving NIH award money (data not shown). In comparison, total nationwide NIH funding increased by an average of 10.2% per year from 1996 to 2005. Thus, the University of Arizona lagged the national average in annual NIH funding growth. It should be noted that the University suffered a decline in NIH funding from 2004-2005. The decline from $112.5M to $108.6M represented a 3.5% decrease, an unusual event considering the overall NIH award funding for the nation increased by 2.2% that year (data not shown).

Table B5: NIH Funding to University of Arizona, 1996–2005



The College of Medicine received $68.7 million in NIH awards in 2005, ranking 55th among medical schools nationwide and accounting for 63.2% of all University of Arizona NIH funds. To understand where the majority of this type of research is conducted within the medical school, we examined the distribution of NIH awards throughout departments. Within the College of Medicine, the Department of Anatomy and Cell Biology received the highest level of NIH funding with $10.8 million, followed by Pediatrics ($6.9 million), Radiation-Diagnostic/Oncology ($6.0 million) and Pharmacology ($5.6 million) (Table B6).

Table B6: University of Arizona College of Medicine NIH Awards, 2005, by Department

Department	Rank Among U.S. Medical Schools in 2005 (Total Awards, Awards Value)
Anatomy and Cell Biology	17th (18 awards, $10,761,354)
Pediatrics	34th (19 awards, $6,900,081)
Radiation-Diagnostic/Oncology	20th (14 awards, $6,012,179)
Pharmacology	31st (21 awards, $5,572,711)
Physiology	47th (16 awards, $4,339,318)
Family Medicine	2nd (9 awards, $3,626,708)
Biochemistry	75th (6 awards, $2,344,737)
Internal Medicine	91st (6 awards, $2,316,347)
Ophthalmology	29th (7 awards, $2,088,632)
Psychiatry	62nd (5 awards, $1,658,207)
Microbiology/Immunology & Virology	83rd (5 awards, $1,450,954)
Surgery	56th (4 awards, $1,273,228)
Pathology	78th (3 awards, $798,488)
Anesthesiology	34th (1 award, $454,371)
Obstetrics & Gynecology	67th (1 award, $256,277)
Orthopedics	32nd (1 award, $228,173)
Other Health Professions	18th (1 award, $102,060)

Significant levels of NIH funding are also received by other schools at the University of Arizona (Table B7). The School of Pharmacy ranked 7th in 2005 among U.S. pharmacy schools in terms of NIH funding, receiving 22 awards totaling $7.8M. The School of Public Health received $3.2M (rank 23rd) and the School of Nursing $812K (rank 48th).

Table B7: Other University of Arizona Schools Ranked by NIH Funding Dollars in 2005

School	Rank Among U.S. Professional Schools in 2005 (Total Awards, Awards Value)
Pharmacy	**7th (22 awards, $7,843,559)**
Public Health	**23rd (10 awards, $3,157,738)**
Nursing	**48th (5 awards, $812,547)**

NSF Biosciences Funding

Data describing active bioscience-related research awards at the University of Arizona and their NSF-specific funding sources were obtained from the NSF website. Table B8 reveals that the primary source of R&D funding came from the NSF Directorate for Biosciences (BIO), which funds much of the nation's research on plant biology, environmental biology and biodiversity. $41.7M in active awards is from this sector. Divisions within the BIO Directorate include the Divisions of Biological Infrastructure, Integrative Organismal Biology, Molecular and Cellular Biosciences, Behavioral and Neural Sciences, and Cellular Biosciences. Of these, the Division of Biological Infrastructure, which supports contemporary research in biology, research resources, human resources and the Plant Genome Research Program, is the largest source of NSF funding to the U of A, with $24.2M in active awards. Other NSF Divisions that fund bioscience-related research at the University of Arizona are the Division of Behavioral and Cognitive Sciences (in the Directorate for Social, Behavioral and Economic Sciences) with $6M in active awards and the Division of Bioengineering and Environmental Systems (in the Directorate for Engineering) with $638K in active awards.

Table B8: Active Bioscience-related NSF Awards at the University of Arizona

NSF Organization	Number of Active Awards	Awarded Dollars
BIO—Directorate for Biosciences	59	41,738,534
• DBI—Division of Biological Infrastructure	15	24,213,673
• IOB—Division of Integrative Organismal Biology	15	6,431,855
• DEB—Division of Environmental Biology	21	4,927,827
• MCB—Division of Molecular and Cellular Biosciences	6	3,808,691
• BNS—Division of Behavioral and Neural Sciences	No data	No data
• DCB—Division of Cellular Biosciences	No data	No data
BCS—Division of Behavioral & Cognitive Sciences (SBE)	28	5,988,481
BES—Division of Bioengineering and Environmental Systems (ENG)	2	638,297

Table B9 summarizes the number and value of NSF bioscience-related research awards to the University of Arizona from 2000 to April 2006. During this period, the University of Arizona captured all but 3 of the bioscience-related NSF research grants in the Tucson/Pima County region.

Table B9: Bioscience-related NSF Research Awards at the University of Arizona, 01/2000 - 04/2006

NSF Directorate	Division	# of Awards	$ Amount	% of Total AZ Amount	% of Total U.S. Amount
Biosciences	Biological Infrastructure	32	$28,265,087	26.9%	0. 85%
	Integrative Organismal Biology	34	$11,021,007	10.5%	0.33%
	Environmental Biology	48	$9,167,396	8.7%	0.28%
	Molecular and Cellular Biosciences	21	$6,141,328	5.8%	0.18%
	Emerging Frontiers	2	$2,335,960	2.2%	0.07%
Engineering	Bioengineering & Environmental Systems	9	$2,360,354	2.2%	0.07%
Total Bioscience-related		**146**	**$59,291,132**	**56.4%**	**1.78%**
Total Bioscience-related for AZ		**277**	**$105,055,591**	**100.0%**	**3.16%**
Total Bioscience-related for U.S.		**10,374**	**$3,329,371,822**	**N/A**	**100.0%**

Over the 6 years measured, the university earned 56.4% of all bioscience-related NSF funding awarded to the state and 1.78% of all bioscience-related NSF funding for the nation.

USDA Biosciences Funding

The USDA funds over $10 million in research at Arizona colleges and universities. USDA funding is particularly important to land grant institutions, such as the University of Arizona, who have substantial R&D infrastructure supporting animal and plant biosciences and associated disciplines. The USDA CRIS database provides information on grants and awards to individual universities. CRIS data reveal that the University of Arizona currently has 257 active awards from the USDA.

Table B10 summarizes USDA award numbers by the recipient department or office at the University of Arizona. These data cover research grant awards for 2000 through 2005.

Table B10: USDA Awards for the University of Arizona, by Department, 2000-2005

University of Arizona Department	Number of Awards
Plant Science	24
Office of Arid Land Studies	10
Entomology	9
Veterinary Science and Microbiology	9
Soil, Water & Environmental Science	5
Yuma Agricultural Center	5
Animal Science	4
Natural Resources	4
Nutritional Sciences	3
Maricopa Agricultural Center	2
N/A	2
Agricultural and Biosystems Engineering	1
Agricultural and Resource Economics	1
Ecology and Evolutionary Biology	1
Family and Consumer Resources	1
Institute for Biomedicine Sciences and Biotechnology	1
Physiology	1
Plant Pathology	1

Core Competency Research Areas Suggested by ISI Citations Data

ISI provides specific insight regarding the volume of publications produced by departments and the influence, in terms of citations, that each department's work is having within its field. The ISI data contributes to an overview of where Southern Arizona's institutional strengths in science and technology may lie.

Battelle accessed the ISI data for 2001 through 2005. In determining areas of strength within Southern Arizona academic biosciences, the focus was on bioscience and related fields in which the University of Arizona has published **at least 50 papers** that meet at least one of the following ISI indices parameters:

- The relative impact of the published papers should be **1.25 or higher**, where 1.0 equals the average impact of a U.S. paper in the field. "Relative Impact" represents the institution's citation impact in the field (number of citations its papers receive in a field divided by its total number of papers) divided by average national impact of a paper in that field. A number above 1.0 can be read as a percentage, i.e., 1.25 equates to a 25 percent higher-than-average impact, while a 0.9 impact is 10 percent lower than average.
- The publication quotient or citation quotient of **1.5 or higher** indicates a concentration of effort in the area within the institution. The ratio measures the degree of concentration in a field within an institution versus the U.S. average. A ratio of 1.0 equals the national average, while greater than 1.0 indicates a higher concentration in Arizona versus the nation.

ISI data for the University of Arizona from 2001-2005 are presented in Table B11, with variables highlighted in red to highlight those bioscience fields for which selection thresholds are met. It is apparent from the publications analysis that the University Arizona has strengths ranging from basic research to applied sciences in human-, animal- and plant-related disciplines. Strengths in neurology/neurosciences and plant sciences are particularly apparent from this analysis. Having strengths across the broad spectrum of human, animal and plant biosciences bodes well for the region in an era where convergence and multi-disciplinary research is generating critically important discoveries and increasingly attracting substantial external research funding.

Table B11: Bioscience Publication Strengths of the University of Arizona

University of Arizona Bioscience Related Fields	Citations	Citations Quotient	Papers	Papers Quotient	U of A Impact Relative to Field
STRENGTH THRESHOLD	**--**	**>=1.5**	**>=50**	**>=1.5**	**>=1.25**
Neurology	1469	1.16	**99**	0.57	**2.26**
Entomology/Pest Control	929	**3.83**	**169**	**1.93**	**2.21**
Ophthalmology	418	**1.21**	46	0.63	**2.15**
Plant Sciences	3078	**2.28**	**273**	**1.31**	**1.95**
Animal & Plant Sciences	2837	**3.33**	**189**	**2.00**	**1.86**
Dermatology	221	0.77	32	0.53	**1.62**
General & Internal Medicine	3345	1.10	**152**	0.80	**1.54**
Medical Research, General Topics	4031	0.85	**181**	0.63	**1.50**
Political Science & Public Administration	186	1.07	**88**	0.82	**1.46**
Hematology	463	0.46	34	0.38	**1.34**
Anesthesia & Intensive Care	739	**1.46**	**126**	**1.23**	**1.32**
Clinical Immunology & Infectious Diseases	991	0.73	**88**	0.62	**1.31**
Psychology	1728	1.04	**375**	0.89	**1.30**
Veterinary Medicine/Animal Health	104	0.31	32	0.29	**1.21**
Pediatrics	492	0.81	**99**	0.76	1.20
Gastroenterology and Hepatology	652	0.81	**62**	0.76	1.19
Neurosciences & Behavior	4924	0.70	**417**	0.66	1.18
Cardiovascular & Respiratory Systems	1614	0.68	**177**	0.65	1.16
Food Science/Nutrition	298	0.65	**65**	0.63	1.15
Biology	2408	**2.04**	**295**	**2.03**	1.12

Table B11: Bioscience Publication Strengths of the University of Arizona (continued)

University of Arizona Bioscience Related Fields	Citations	Citations Quotient	Papers	Papers Quotient	U of A Impact Relative to Field
Agricultural Chemistry	218	1.02	44	1.01	1.12
Medical Research, Organs & System	2326	0.69	292	0.69	1.12
Oncology	2356	0.81	174	0.82	1.10
Chemistry	1900	0.75	157	0.81	1.03

Some fields stand out as primary strengths, or areas in which the university published and was cited frequently, while other fields could be considered secondary strengths due to less frequent, but still noteworthy, publications and citations. Three fields in which the University of Arizona published fewer than 50 papers but experienced high impact were also apparent. These results are depicted in Table B12.

Table B12: Strength of Research at the University of Arizona Determined by Publication and Citation Metrics, by Field

Field	Primary Strength	Secondary Strength	Low Publication/ High Impact
Neurology	✓		
General & Internal Medicine	✓		
Anesthesia & Intensive Care	✓		
Clinical Immunology & Infectious Diseases	✓		
Chemistry	✓		
Entomology/Pest Control	✓		
Animal and Plant Sciences	✓		
Plant Sciences	✓		
Psychology		✓	
Biology		✓	
Ophthalmology			✓
Dermatology			✓
Hematology			✓

The ISI citations analysis highlights several factors relating to the biosciences in Southern Arizona:

- There is significant institutional depth in a broad range of bioscience, biomedical and related disciplines such as chemistry.
- The University of Arizona has strengths in the three primary components of bioscience: human medicine, animal science, and plant sciences/agricultural science.
- Ophthalmology, dermatology and hematology may represent emerging research strengths.

Research Core Competency Areas Suggested by OmniViz™ Cluster Analysis

Battelle, through its research at the Pacific Northwest National Laboratory (PNNL), developed proprietary pattern recognition and clustering software that provides unique insight into research strength areas. As a result of this research, and the associated software development, Battelle subsequently developed a separate company to commercialize the software. The spin-off company and the cluster analysis tool are both named OmniViz™.

Figure B4: Statewide Research Core Competency Areas Suggested by OmniViz™ Cluster Analysis

OmniViz™-based Core Competency Areas

- Cancer Research
- Neurosciences
- Basic Molecular & Genomic Sciences
- Plant Sciences
- Environmental Sciences
- Behavioral Sciences & Community Health
- Bio-Imaging
- Infectious Diseases & Vaccine Development
- Cardiovascular Development & Repair
- Asthma & Inflammatory Processes

OmniViz™ uses pattern recognition algorithms to cluster research fields into grouped strength areas. This software is valuable because it allows free association of words and phrases, rather than forcing clustering on preselected key words—thus, there is no *a priori* bias to the clusters identified.

Battelle performed the cluster analysis on a statewide basis for all NIH, NSF, USDA and Arizona Biomedical Research Commission grants awarded from October of 2000 through May of 2005 (Figure B4 sets out a summary of the core competency areas identified). Altogether the Arizona grants analysis dataset contained detailed abstract information for 1,696 grants awarded of which the University of Arizona represented 1082 or 64% of the total analyzed. The breakout by funding agencies of the research grants is:

- NIH—1,056 grants
- USDA—154 grants
- NSF—277 grants (only bio/agriculture-oriented grants were used for this analysis)
- ABRC—209 grants

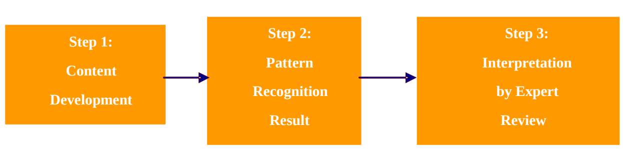
The performance of the clustering analysis involved the following steps (Figure B5):

Step 1—Content Development: Developing a data set with sufficient descriptive content, such as patent abstracts or grant abstracts. OmniViz™ cannot work with only titles or single sentence descriptions.

Step 2—Pattern Recognition: The analysis generates clusters where patents or grant activity have apparent relationships and produces a series of words to describe and link these cluster areas.

Step 3—Interpretation and Grouping by Expert Review: Identification of key themes and groupings that result from OmniViz™ requires an experienced research analyst to interpret and explain the types of technologies and specific activities that are represented in the cluster items.

Figure B5: Method for Applying Cluster Analysis



OmniViz™ output was provided to the analyst in both graphical and spreadsheet table formats. This allows for visualization of key cluster areas and then deeper investigation of the actual grants or patent information contained within each apparent cluster. The analysis resulted in the generation of 61 clusters, and careful review of these clusters revealed 10 meta-cluster groupings or "themes." Of these, 6 themes were extensive or broad-based, comprised of 134 or more grant awards, and 4 were niche-oriented, comprised of 51 or fewer awards. These themes represent statewide research strengths. However, the University of Arizona was awarded the majority of grants in each theme, demonstrating the university's broad research capabilities across the bioscience spectrum. The U of A accounted for 77.5% of all grant awards in the Cancer Research meta-cluster, 71.5% of all grant awards in the Basic Molecular & Genomic Sciences meta-cluster, and 71.4% of the awards in the Cardiovascular Development and Repair meta-cluster. Additional details of these themes are shown in Tables B13 and B14.

Table B13: Summary of Extensive Cluster Themes Containing >134 Grants

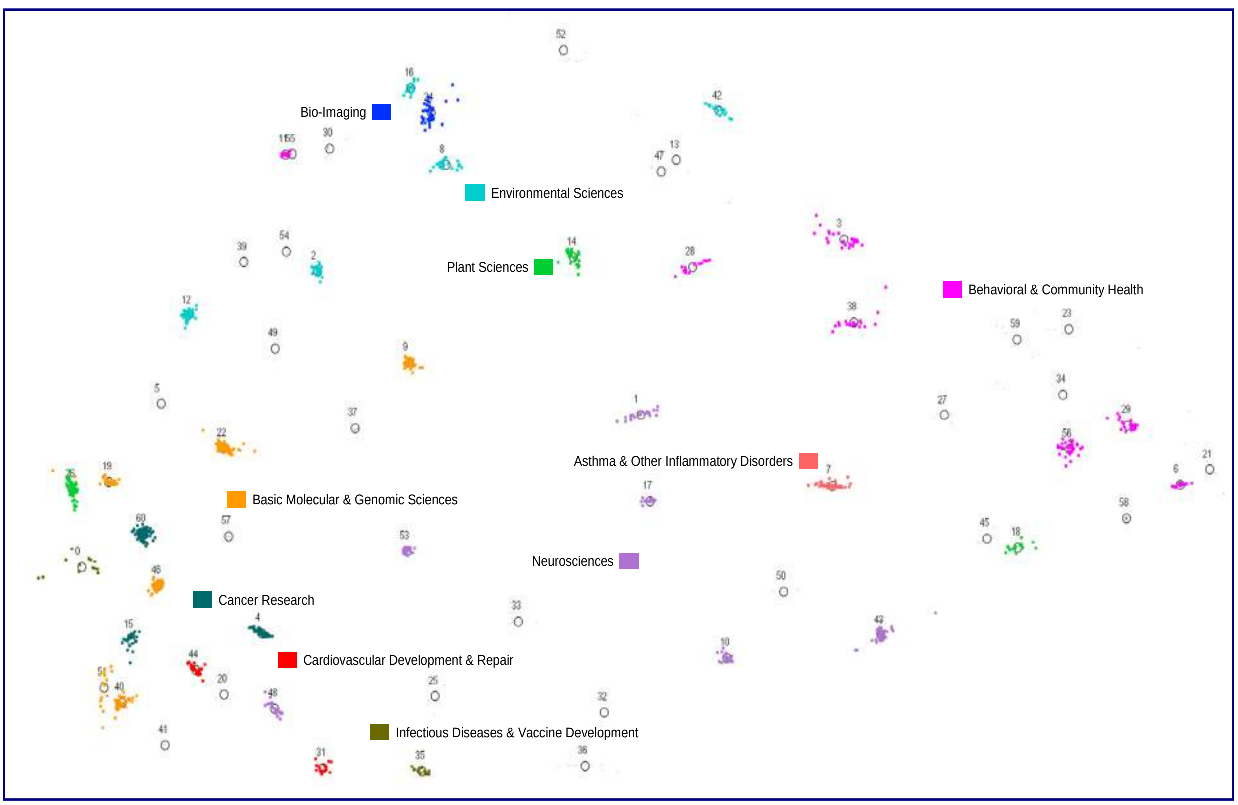
Meta-Cluster Title	Key Terms	Number of Clusters	Number of Grants	Number of Grants Awarded to U of A (% of Total)
Cancer Research	Cancer prevention, diagnostics, therapeutics	5	307	238 (77.5%)
Neurosciences	Neurobiology, neuropharmacology, brain function, pain, stroke, speech & hearing, aging	10	233	130 (55.8%)
Basic Molecular & Genomic Sciences	Gene regulation, gene expression, structural/functional genomics, signal transduction, protein structure and function	7	445	318 (71.5%)
Plant Sciences	Plant genetics, host-organism interactions, pest control and resistance, food safety, horticulture	7	134	69 (51.5%)
Environmental Sciences	Population dynamics, ecosystem studies, soil biology, environmental toxicology, arid lands	9	159	91 (57.2%)
Behavioral Sciences & Community Health	Prevention studies, mental health, diabetes education and prevention, Hispanic outreach, Native American outreach	8	185	96 (51.9%)

Table B14: Summary of Niche-oriented Cluster Themes Containing <51 Grants

Meta-Cluster Title	Key Terms	Number of Clusters	Number of Grants	Number of Grants Awarded to U of A (% of Total)
Bio-Imaging	Medical imaging, image processing, biosensors, cell imaging	2	50	32 (64.0%)
Infectious Diseases & Vaccine Development	Bacterial pathogens, viral infections, vaccine development	2	33	17 (51.5%)
Cardiovascular Development & Repair	Cardiovascular grafts, implants, birth defects, micro-circulation, resuscitation, cellular mechanisms	2	49	35 (71.4%)
Asthma & Inflammatory Processes	Longitudinal studies, innate immunity, inflammatory mechanisms, anti-inflammatory agents	1	51	35 (68.6%)

The results of the cluster analysis are presented in Figure B6 as a cluster "map." The map illustrates the size and density of each cluster as well as the "relatedness" of each cluster to other clusters. Clusters that are nearer one another on the map are typically more closely related by subject.

Figure B6: Cluster Map of Arizona Grant Awards from 10/2000—5/2005



OmniViz™ analysis of research grant awards demonstrates strength in a number of fields across the bioscience spectrum. Cluster themes in cancer research, neurosciences, infectious diseases & vaccine development, cardiovascular development & repair, and asthma & inflammatory processes reflect an emphasis on biomedical research while cluster themes in plant sciences and environmental sciences indicate emphasis on agriculture-related research. Behavioral sciences & community health may reflect a push towards serving the biomedical needs of underserved populations. Basic molecular & genomic sciences and bio-imaging may be better characterized as platforms, rather than individual core competencies, because awards in these cluster themes were scattered throughout many different institutions and institutional departments indicating that these fields are cross-cutting by nature.

CORE COMPETENCY RESEARCH AREAS SUGGESTED BY ISSUED PATENTS

Battelle also investigated Southern Arizona patent data in order to identify key areas of R&D that yield intellectual property. Between 2000 and April of 2006, 424 bioscience-related patents were either invented in or assigned to the Southern Arizona region. This dataset reflects the intellectual property that either generated in the region, brought into the region by way of purchasing rights, or both. Table B15 depicts the bioscience patent classes in which at least 5 patents were issued. Table B16 depicts the inventors and/or assignees who obtained at least 5 bioscience-related patents from 2000—4/2006.

Table B15: Bioscience-related Patents Invented by or Assigned to a Southern Arizona Research Organization or Institution, by Field (2000 - 4/25/2006)

Key U.S. Patent Class	# of Patents
Drug, bio-affecting and body treating compositions	179
Surgery	63
Chemistry: molecular biology and microbiology	45
Multicellular living organisms and unmodified parts thereof and related processes	17
Chemistry: analytical and immunological testing	16
Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof	15
Organic compounds -- part of the class 532-570 series	15
Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	13
Medical and laboratory equipment	11

Table B16: Southern Arizona Organizations or Institutions where >5 Bioscience Related Patents were Invented or Assigned (2000 - 4/25/2006)

Organization/Institution	# of Patents
Research Corporation Technologies, Inc.	59
University of Arizona	40
Ventana Medical Systems, Inc.	25
ImaRx Pharmaceutical Corp.	21
UAF Technologies and Research, LLC	13
Aventis Pharma Deutschland GmbH	11
ImaRx Therapeutics Inc.	10
Abbott Laboratories	8
Engineering & Research Associates, Inc.	7
Bristol-Myers Squibb Medical Imaging, Inc.	7
Aventis Pharmaceuticals Inc.	7
Endoluminal Therapeutics, Inc.	6
Desert Whale Jojoba Company, Inc.	6
BASF Plant Science GmbH	6
University of Kentucky Research Foundation	5
Thayer Medical Corporation	5

Patent data indicate that most Southern Arizona bioscience-related patents are composition patents claiming invention of drugs or other biological or chemical compounds. A significant number of patents in the class of Surgery indicates that the region has a strong base in the development of new surgical methods and/or products. These observations are supported by the list of commercial organizations where most of these patents were invented or assigned; many operate in the medical equipment industries.

In 2005, the majority of U.S. patents filed by the University of Arizona were from the Arizona Cancer Center, BIO5 and College of Optical Sciences (FY2005 University Technology Transfer Reports).

CORE COMPETENCY RESEARCH AREAS SUGGESTED BY REPUTATION

Examining publications or research grants (either through funding levels or context, as in the case of cluster analyses) provides a certain perspective for establishing Arizona's R&D core competencies. However, given that some unique strengths may also exist without a strong direct tie to research publications or funding mechanisms it is important to look beyond these types of analyses to determine such strengths. One method is to use third-party-based reputation analyses, such as the *U.S. News & World Report's* Graduate School Rankings and Best Hospitals Rankings.[27] These rankings, while typically geared more toward the general public, often help establish areas of strength in the less research-intensive areas.

Table B17 details the rankings of bioscience-related fields of graduate study within the University of Arizona, as listed by the 2007 *U.S. News & World Report* rankings of best graduate schools. The

[27] *U.S. News & World Report* methodology for identifying "America's Best Hospitals" was devised in 1993 by the National Opinion Research Center at the University of Chicago, which carries it out and refines it each year. The U.S. News Index accounts for reputation cited by a random sample of board-certified physicians in each specialty area over the past three years as well as data from an annual survey of hospitals by the American Hospital Association, generally covering extensiveness of services.

university's graduate program in Biological Sciences: Ecology/Evolutionary Biology ranked 13th and is consistently perceived as being one of the strongest programs in the nation. Graduate programs in Family Medicine and Environmental Engineering/Environmental Health also rank high—22nd and 23rd in the nation, respectively.

Table B17: University of Arizona Bioscience-related Academic Reputation (2007 *U.S. News & World Report* Graduate Ranking and Peer Assessment Score)

Field	Rank	Peer Assessment Score (out of 5)
Biological Sciences: Ecology/Evolutionary Biology	13	N/A
Medicine: Family Medicine	22	N/A
Engineering: Environmental/Environmental Health	23	3.3
Biological Sciences (Ph. D)	36	3.6
Chemistry (Ph. D)	38	3.4
Engineering: Chemical	51	2.7
Medicine	57	2.9

Table B18 lists the 2006 *U.S. News & World Report* rankings for Arizona hospital and clinical care institutions. The University Medical Center in Tucson achieved high rankings in a number of fields. Rankings are based on reputation, mortality, and a mix of care-related factors such as nursing and patient services. Reputation score is the percentage of responding physicians who named the institution among the 5 best in the field.

Table B18: University Medical Center, Tucson, Hospital/Clinical Care Reputation (2006 *U.S. News & World Report*)

Field	Rank	Reputation Score
Heart and Heart Surgery	16	0.7%
Respiratory Diseases	20	1.0%
Cancer	22	0.9%
Neurology and Neurosurgery	22	1.1%
Urology	26	0%
Kidney Disease	39	0%
Orthopedics	41	1.3%
Digestive Disorders	45	0.3%

Summary of Core Competency Areas Suggested by Quantitative Analysis

The quantitative data sources (grant awards, ISI publications and citations, and cluster analyses) provide considerable insight into the R&D strengths of Southern Arizona in the biosciences and related fields. Contained within these data are broad themes that serve as "direction finders" to the state's bioscience core competencies (both broadly based and human medicine/health specific). Table B19 details each of the broadly based core focus areas and expertise areas suggested by the quantitative data.

Table B19: Broadly Based Core Focus Areas Suggested by Quantitative Data

Core Focus Area	Federal Research Grants			Publication & Citation Strength	*OmniViz™* Cluster: Grants	Patents	Academic Reputation	
	NIH	NSF	SDA				Grad	Hosp
Cancer Research	✓				✓			✓
Neurosciences	✓			✓	✓			✓
Plant Sciences			✓	✓	✓			
Insect Sciences			✓	✓	✓			
Agricultural Sciences			✓		✓			
Environmental Eco-sciences		✓	✓		✓		✓	
Pharmacy/ Pharmaceutics	✓					✓		
Basic Molecular & Genomic Sciences	✓	✓	✓		✓		✓	
Asthma/Inflammatory Processes	✓				✓			✓
Bio-Imaging	✓				✓			
Cardiovascular Development/Repair	✓				✓			✓
Bioengineering	✓	✓			✓	✓		
Behavioral Sciences & Community Health	✓	✓			✓			
Basic Physical Sciences	✓			✓		✓	✓	
Applied Math & Biomathematics	✓							
Infectious Diseases	✓			✓	✓			
Diabetes	✓							

The core focus areas resulting from the Southern Arizona quantitative analysis are used to direct the focus of field-work interviews for additional investigation, and identify core competencies and technology platforms.

The following section details Battelle's findings from the qualitative interview research conducted with bioscience institutions in the Southern Arizona region. Both the quantitative and qualitative findings are evaluated by Battelle experts to determine core technology platforms upon which bioscience development may be built. The technology platforms are discussed in detail in the following sections of this document.

Qualitative Assessment of the Region's Bioscience Base: Interview and Fieldwork Findings

The analysis of grant, publishing, and research abstract data provides a context for understanding where Southern Arizona's core competencies in bioscience research are focused. To further investigate these fields and deepen our understanding of the core bioscience research competencies in Southern Arizona, extensive interviews were conducted with university administrators, faculty, scientists, clinicians, industry executives, and development agencies in the region. These interviews were essential in developing an understanding of how the data on publications, patents and grant awards translate into on-the-ground focus areas in Southern Arizona.

In total, telephone interviews and face-to-face interviews individually or in small group sessions were conducted with more than 100 individuals, including senior academic research scientists and faculty at the University of Arizona and the Southern Arizona VA Hospital. Key takeaways from these interviews and from interviews with commercial bioscience-related companies and associated industry promotion and economic development groups contributed to the identification and analysis of core competencies.

The interviews partly confirmed the areas where Southern Arizona possesses research strength that were identified in the quantitative analysis. They also highlighted several new and emerging areas of R&D and some key theme areas that were not readily apparent within the quantitative datasets. One challenge in using quantitative data is the rapid rate of change in the scientific enterprise. Peer review systems—whether used for federal grant awards, citation analysis, or in reputation rankings—tend to lag emerging new fields of inquiry, and may fail to recognize the contributions of younger and new scientific talent. Therefore, one objective of the qualitative interviews was to capture emerging areas, faculty, and fields of inquiry at each of the subject institutions.

The core content of the field interviews was synthesized and key areas of research strength and expertise were identified. Both these qualitative interviews and the quantitative research are of substantial importance in determining core competencies—they go hand-in-hand to facilitate identification of:

- Where Southern Arizona is heading in terms of building upon and leveraging its core bioscience strengths, and developing and enhancing new and emerging areas of bioscience focus
- What the current pipeline of bioscience R&D activity is within academic research institutions in the region
- Which areas of bioscience are generating patents and intellectual property that can lead to commercial opportunities for Southern Arizona

The field interviews provide information relevant to each of these question categories, but they are most important in providing an in-depth understanding of current and emerging R&D strengths and opportunities.

Based on the interviews, and in reference to the quantitative analysis, findings were organized into three basic levels:

Established Strengths in which Southern Arizona has considerable presence through at least two of the following:

- A significant number of well-funded researchers, scientists and/or clinician scientists working in basic, applied, or clinical research
- Recognized clinical expertise
- Applied science R&D assisting critically important current and/or emerging commercial sectors
- A number of commercial enterprises with R&D or production facilities working on the delivery of products or services

Significant Presence areas in which Southern Arizona has demonstrated strengths that are more focused on one dimension or which have lower levels of research activity, clinical expertise, or commercial enterprises, or have a more niche focus of activity. In many instances, these include research areas that are required to support other areas of strength, or to form platforms for economic development from the biosciences. As such, these are highly important strengths to continue building.

Emerging are smaller or more embryonic programs that show potential for future bioscience development in the region.

Based on these general parameters, the team identified the following research competency areas (Table B20):

Table B20: Southern Arizona Core Competency Areas

Established Strengths	Areas with Significant Presence	Emerging
• Cancer Research	• Cardiovascular Development/ Repair	• Diabetes Research
• Neurosciences	• Bioengineering	• Infectious Diseases & Vaccine Development
• Plant Sciences	• Basic Physical Sciences	
• Basic Molecular & Genomic Sciences	• Applied Math & Biomathematics	
• Agricultural Sciences	• Behavioral Sciences & Community Health	
• Insect Sciences		
• Environmental Eco-Sciences		
• Pharmacy/Pharmaceutics		
• Bio-Imaging		
• Asthma & Inflammatory Processes		

It must be recognized that many of the established, significant presence and emerging strength areas are supported by considerable investment and expertise contained within multiple cross-cutting areas of science and technology. Researchers in basic molecular and genomic sciences, insect sciences, and bio-imaging form distinct clusters of expertise that produce important fundamental and applied discoveries in their own right, but also provide foundational support for the core competency areas. **Strengths in these areas and the underlying science fabric of Southern Arizona's biosciences must continue to be built in order for core competencies to be sustained, supported and exploited.**

It should also be noted that in modern biosciences it is seldom the case that an area of focus stands on its own. Rather, just as organisms form complex systems, bioscience itself should be viewed as a complex system of interrelated disciplines and areas of study that support and assist in the advancement of one another. It is for this reason that the NIH and similar funding organizations are focusing increasing grant-making attention on interdisciplinary institutes, centers and research teams. As such, the formation of focused interdisciplinary teams, centers and institutes should be an institutional imperative for success in accessing large-scale federal grant funding.

The links that exist and form between strength areas are critical to the emergence of bioscience core competencies in Southern Arizona. As in any system, a change in one of the parameters (strength areas) is likely to affect the operation of others. For example, a center for the support of biosensor development may increase the attention of various medical, veterinary and agricultural sub-disciplines on applications of advanced sensors in their work. Likewise, a center for the study of novel drug delivery methods might stimulate interdisciplinary teams to form around applications to cancer, cardiovascular disease or neuro-degenerative diseases.

The team examined the main bioscience strength areas that were identified for Southern Arizona. Each of the areas was summarized in terms of:

- A definition of the field or specialty area
- A general profile of the sub-disciplinary strengths evident in the region
- Supporting quantitative statistics (where available)
- Details regarding the strengths in Southern Arizona that were identified by interviewees

Table B21: Established Strength Area: Cancer Research

Cancer Research		
Overview		Cancer is a term used to describe over 100 diseases characterized by abnormal and uncontrolled division of cells and the ability of these cells to invade other tissues. Cancer research encompasses activities ranging from diagnostics to therapeutics to prevention.
Presence in Cluster Analysis		5 clusters; 307 grants
Competitive Position	Research Funding	• U of A College of Medicine Dept. of Radiation-Diagnostic/Oncology: 14 NIH awards for $6.0M in FY2005, ranking 25th among U.S. medical schools • U of A Comprehensive Cancer Center ranks 15th among the 39 national cancer centers in terms of NCI funding; ranks 5th on a funding/faculty member basis
	Publications Analysis	174 papers in Oncology published in 2001-2005; impact relative to field of 1.10
	Reputation Standing	University Medical Center in Tucson ranked 22nd nationwide for Cancer Care by 2006 *U.S. News & World Report*
	Major Funded Centers or Programs	• NCI-designated Arizona Cancer Center at the College of Medicine • New cancer clinical center being opened to address small size of existing clinical facilities
Insights from and Niches Identified from Interviews		• Specializations in gastrointestinal (GI), prostate and skin cancer; ongoing translational research • Lymphoma is a historic strength • Emerging focus in pancreatic cancer • New research initiative at the AZ Cancer Center focusing on breast cancer in Latinas, sponsored by the Avon Foundation • Strengths in molecular target identification; imaging; therapeutic agent discovery and development. Several spin out companies based on drug development. • Design of peptide drugs is a strength; draws on linkages to the chemistry department • Southern AZ VA hospital strong in cancer prevention research; also palliative care for cancer patients • Linked with the Southwest Center for Natural Products Research and Commercialization, which researches anti-cancer compounds from arid land organisms • Linked with biomedical engineering primarily for development of imaging techniques • Linked with other fields on campus as well, including plant sciences and plant epigenetics, environmental studies, nutrition • Extremely interdisciplinary—spans basic, translational and clinical research; 30 out of 143 researchers are involved in translational efforts • Emerging strengths in cancer genomics and proteomics • Draws on genomic capabilities at ARL • Emerging focus on arsenic in cancer cell signaling • Knockout mouse capabilities

	• Researchers in School of Nursing using genomics to understand effects of chemotherapy • Key opportunity emerging from FDA's requirement that each cancer drug is accompanied by a biomarker information, so that the efficacy of the drug can be monitored • Linked to C-Path Institute for testing and clinical development

Table B22: Established Strength Area: Neurosciences

Neurosciences		
Overview		Neuroscience is the discipline concerned with the development, structure, function, chemistry, pharmacology, clinical assessment, and pathology of the nervous system.
Presence in Cluster Analysis		10 clusters; 233 grants
Competitive Position	Research Funding	• U of A College of Medicine Dept. of Ophthalmology: 7 NIH awards for $2.1M in FY2005, ranking 29th among U.S. medical schools • U of A College of Medicine Dept. of Anesthesiology: 1 NIH award for $454K in FY2005, ranking 34th among U.S. medical schools
	Publications Analysis	Primary publication strength with 99 papers in Neurology published in 2001-2005; impact relative to field of 2.26 (the highest of any field at the U of A). 417 papers in Neurosciences & Behavior published; impact relative to field of 1.18.
	Reputation Standing	University Medical Center in Tucson ranked 22nd nationwide for Neurology and Neurosurgery by 2006 *U.S. News & World Report*
	Major Funded Centers or Programs	• Evelyn F. McKnight Brain Institute within the ARL; goal is to foster interdisciplinary research focusing on the neural basis of age-related cognitive changes • The Arizona Alzheimer's Disease Core Center (AACC) received a five-year, $7.5 million grant from the National Institute on Aging (NIA) to continue its collaborative Alzheimer's research; U of A and Southern AZ VA Hospital are members of the center
Insights from and Niches Identified in Interviews		• Core strengths in neurodevelopment and model systems; neurodegeneration and aging; movement disorders; vision; cognition, memory and learning • Basic science of normal aging • Focus on basic mechanisms of brain aging; Alzheimer's research is a statewide strength • Strengths in cognitive neurosciences, linguistics, motor control, psychology, speech and hearing • Some research in regenerative medicine, stem cell work • Very small but strong research group studying pain using rats as models • Use of insects as model systems for neurobiology work is starting to yield some technologies • Able to record from more cells simultaneously than any other place in the world • Links with local biotech and med device companies on developing more sophisticated whole-brain imaging processes, automation, real-time imaging • Links to researchers in psychology, psychiatry. Neuropsychology is strong. • Relatively new focus on neurotherapeutics with models for neurodegenerative diseases • Ophthalmology tie-in via neurodegenerative diseases of the eye—extremely strong group in macular degeneration • Psychiatry is mostly clinical research-oriented

Table B23: Established Strength Area: Basic Molecular & Genomic Sciences

Basic Molecular & Genomic Sciences		
Overview		The molecular sciences include chemistry, biochemistry, genetics and physics; within the biosciences, the molecules that are investigated include those that make up genetic information and proteins. Genomic sciences span the mapping and sequencing of genomes, cloning, analysis of gene function, proteomics, medical genetics, computational modeling and other areas in which the goal is to exploit the information contained in genomes for the improvement of health, agriculture and the environment.
Presence in Cluster Analysis		7 clusters; 445grants
Competitive Position	Research Funding	Federal funding for biological sciences at U of A in FY2003 was $45.8M
	Publications Analysis	Secondary publication strength with 295 papers in Biology published in 2001-2005; impact relative to field of 1.12
	Reputation Standing	University of Arizona PhD program in Ecology/Evolutionary Biology ranked 13th nationwide by 2006 *U.S. News & World Report*; PhD program in Biological Sciences ranked 36th nationwide
	Major Funded Centers or Programs	• NSF-supported IGERT program in Evolutionary, Functional and Computational Genomics • Newly formed Arizona Proteomics Consortium (includes facilities from BIO5, ARL, Department of Chemistry, Arizona Cancer Center, and Southwest Environmental Health Sciences Center)—will serve as the mass spectrometry and proteomics core for the Pacific Southwest Regional Center of Excellence in Biodefense and Emerging Infectious Diseases
Insights from and Niches Identified in Interviews		• Evolutionary developmental biology and evolutionary genetics & genomics are exceptionally strong • Microbial genomics very strong • University of Arizona is home of the national Drosophila stock center • Draws on services and support offered by the ARL—imaging, genomics, flow cytometry, biocomputing, etc. • BIO5 is a driver of new initiatives and linkages across departments and programs; BIO5 and ARL collaboration is strong • Nitric oxide biology is an example of a focus area with diverse people coming together • Linkages between Biochemistry and Molecular Biophysics, Molecular and Cellular Biology, neurosciences, insect sciences, cancer center, College of Medicine, respiratory science; could benefit from stronger linkage with Department of Chemistry

Table B24: Established Strength Area: Plant Sciences

Plant Sciences		
Overview		Plant Sciences encompass all aspects of the biology of plants including development, photosynthesis, metabolism, cell structure and function, ecology, evolution, genomics and pathology.
Presence in Cluster Analysis		7 clusters; 134 grants
Competitive Position	Research Funding	$17M in external research funding in 2005 (4th highest on campus)
Competitive Position	Publications Analysis	Primary publication strength with 273 papers in Plant Sciences published in 2001-2005; impact relative to field of 1.95
Competitive Position	Reputation Standing	No data
Insights from and Niches Identified in Interviews		• Core strengths include plant genetics/genomics (particularly well known for work in rice and corn); epigenomics; plant transformation; stress and drought tolerance; RNAi; chromatin structure and gene regulation • Complementary College of Agriculture and Life Sciences strengths in soil science, water science, horticulture, and controlled environment agriculture • Very strong sequencing capacity, microarray capacity, but needs stronger support in biostatistics and infomatics • Two National Academy members at the University of Arizona are in this field • Draws on services and support offered by the ARL—imaging, genomics, flow cytometry, biocomputing, etc.

Table B25: Established Strength Area: Agricultural Sciences

Agricultural Sciences		
Overview		Research in agricultural sciences focuses on the improvement of stable and productive agricultural systems, the development of new agricultural products, improving the nutritional value of food, and fostering sustainable, environmentally sound agricultural processes.
Presence in Cluster Analysis		N/A
Competitive Position	Research Funding	Federal funding for agricultural sciences at U of A in FY2003 was $24.8M
	Publications Analysis	Primary publication strength with 189 papers in Animal and Plant Sciences published in 2001-2005; impact relative to field of 1.86
	Reputation Standing	No data
Insights from and Niches Identified in Interviews		• Significant strengths in applied soil and water sciences • Animal sciences are not particularly strong with the exception of some work on animal GI infectious diseases, bull fertility, brine shrimp research • U of A's Controlled Environment Agriculture Center is a unique asset in the region; fosters interdisciplinary research on economically, environmentally and socially sustainable agriculture • Nutraceuticals/functional foods is emerging

Table B26: Established Strength Area: Environmental & Eco-Sciences

Environmental & Eco-Sciences		
Overview		The fields of ecology, geology, water sciences and atmospheric sciences fall within the broader scope of environmental sciences. Interdisciplinary approaches to studying these fields are used to investigate issues such as environmental health, climate change, biodiversity, natural resources, sustainability and pollution.
Presence in Cluster Analysis		9 clusters; 159 grants
Competitive Position	Research Funding	Federal funding for environmental sciences at U of A in FY2003 was $7.0M NIEHS funding for toxicology work (performed in the School of Pharmacy)
	Publications Analysis	No data
	Reputation Standing	University of Arizona PhD program in Environmental Engineering/Environmental Health ranked 23rd nationwide by 2006 *U.S. News & World Report*
	Major Funded Centers or Programs	Southwest Environmental Health Sciences Center awarded $7.8M for 5 years from the NIEHS; will focus on biomarkers as predictors of susceptibility to health effects of environmental agents Office of Arid Land Studies Arizona Water Institute
Insights from and Niches Identified in Interviews		• Strengths in environmental toxicology; environmental engineering; climate change and global monitoring; hydrology, water resources and arid lands • Semi-arid ecology and hydrology (best hydrology department in the nation) • Very good capabilities in hydrology in mathematical modeling • Strong cross-disciplinary linkages • No commercial spin-outs in the last 20 years • Research on ecological impact of transgenic plants is especially strong

Table B27: Established Strength Area: Pharmacy/Pharmaceutics

Pharmacy/Pharmaceutics		
Overview		Pharmacy is the field concerned with the discovery, development, production and distribution of drugs for the purposes of diagnosing, preventing or curing diseases. Pharmaceutics is the discipline within pharmacy that broadly focuses on the development of novel compounds or new chemical entities into safe and effective drugs.
Presence in Cluster Analysis		N/A
Competitive Position	Research Funding	College of Pharmacy ranked 6th nationwide in NIH funding, earning $9.6M in 2004 U of A College of Medicine Dept. of Pharmacology: 21 NIH awards for $5.6M in FY2005, ranking 31st among U.S. medical schools
	Publications Analysis	No data
	Reputation Standing	U of A School of Pharmacy ranked 7th nationwide by *U.S. News & World Report*
	Major Funded Centers or Programs	
Insights from and Niches Identified in Interviews		• Known for work in drug discovery and development • A few local startups working in drug discovery and development • Focus on small molecule anticancer drugs, solubility, dosage—this had led to products • Strengths in environmental toxicology (joint work with other departments on campus, Mexico) • “Birthplace of pharmacoeconomics” • Nutraceuticals focus is emerging • Trying to push towards molecular targeted therapeutics, working with Department of Chemistry • No drug manufacturing capabilities in the region • Could pursue stronger linkages with plant science and insect science groups on campus • Several anticancer agents developed here are in phase I and II clinical trials • Local business Integrated Biomolecule Corp. recently launched a pharmaceutical analysis group

Table B28: Established Strength: Asthma & Inflammatory Processes

Asthma & Inflammatory Processes		
Overview		Asthma is a chronic or recurring inflammatory disease in which the airways constrict and become inflamed in response to various environmental or biological triggers. The disease is complex and involves multiple genetic, environmental and developmental factors. Inflammation is an important feature of asthma and other diseases such as arthritis and Crohn's disease, and knowledge of the mechanisms involved in inflammatory processes may be valuable in the development of treatments and preventions.
Presence in Cluster Analysis		1 cluster; 51 grants
Competitive Position	Research Funding	U of A College of Medicine Dept. of Physiology: 16 NIH awards for $4.3M in FY200, ranking 47th among U.S. medical schools
	Publications Analysis	177 papers in Cardiovascular & Respiratory Systems published in 2001-2005; impact relative to field of 1.16
	Reputation Standing	University Medical Center in Tucson ranked 20th nationwide for Respiratory Diseases by 2006 *U.S. News & World Report*
	Major Funded Centers or Programs	Arizona Respiratory Center at the College of Medicine
Insights from and Niches Identified in Interviews		• Epidemiologic studies that link asthma incidence to biomarkers • Population studies that complement genetic data • Southern AZ VA hospital exceptionally well known for research of GI diseases such as Barrett's esophagus, which is associated with inflammation

Table B29: Established Strength: Bio-Imaging

Bio-Imaging		
Overview		Imaging is the capture, storage, manipulation, and display of visual information or data, which in the biosciences may be achieved through a variety of means including microscopy, x-rays, PET scans, fluoroscopy, MRI and other techniques. Bio-imaging is the broader term that encompasses optical imaging, nuclear imaging, MRI and ultrasound.
Presence in Cluster Analysis		2 clusters; 50 grants
Competitive Position	Research Funding	No data
	Publications Analysis	No data
	Reputation Standing	No data
	Major Funded Centers or Programs	Center for Gamma Ray Imaging funded by National Institute of Biomedical Imaging and Bioengineering (NIH)
Insights from and Niches Identified in Interviews		• Broad capabilities in R&D and applications of multiple technologies, including gamma-ray imaging and nuclear medicine; infrared; optical imaging; image/signal processing and analysis; endoscopic imaging; cancer imaging; small animal cardiovascular imaging; state-of-the-art technologies such as optical coherence tomography • Imaging group in close contact with both physicians and basic scientists from a number of fields, facilitating the development of enabling technologies and the application to specific medical problems • Strong ties with Engineering and Medicine • Strong industry relationships; major linkages with large imaging companies such as GE, Siemens • Ventana Medical Systems one of the success stories • “Optics Valley” local industry cluster • Imaging work to study aging and Alzheimer’s disease is very strong at U of A • Special recognition for work in gamma ray imaging technologies—considered to be at the leading edge • Both Cancer Center and Heart Center are key partners—lots of cardiac small animal imaging; also strong partnerships with ophthalmology and pathology • Good ties with Speech & Hearing, ophthalmology, psychology investigators in depression (functional MRI), stress and coping, family, child and adolescent

Table B30: Established Strength: Insect Sciences

<table>
<tr><th colspan="3">Insect Sciences</th></tr>
<tr><td colspan="2">Overview</td><td>Insect sciences pertain to the study of all aspects of the biology of insects, including their behavior, development, physiology, genetics, evolution, etc. Applications of such research may be made through interdisciplinary studies, which investigate areas of medicine and biotechnology by employing insects as model systems.</td></tr>
<tr><td colspan="2">Presence in Cluster Analysis</td><td>N/A</td></tr>
<tr><td rowspan="4">Competitive Position</td><td>Research Funding</td><td>Mostly NIH, also DARPA, ONR, NSF, private and foundations</td></tr>
<tr><td>Publications Analysis</td><td>Highly cited work on insect resistance to genetically modified crops</td></tr>
<tr><td>Reputation Standing</td><td>Primary research strength with 169 papers in Entomology/Pest Control published in 2001-2005; impact relative to field of 2.21</td></tr>
<tr><td>Major Funded Centers or Programs</td><td>Center for Insect Sciences (CIS); coordinated with Department of Entomology at U of A
USDA lab in Department of Entomology with focus on Africanized Bees</td></tr>
<tr><td colspan="2">Insights from and Niches Identified in Interviews</td><td>• Primary focus is basic science, but there are growing numbers of applications
• Key is the broader use of insects beyond traditional entomology
• Core strengths in engineering applications (materials, robotics, biomechanics, model systems); biomedical applications (vector-borne diseases, neurobiology and model systems); agricultural and environmental applications (plant-insect interactions and resistance, climate change indicators, household pests); systematics
• World-leading, large and unique cluster of insect scientists
• Many innovation-based/commercialization economic opportunities
• Complementary strengths at ASU in social insect biology (member of CIS)
• National Drosophila stock center housed at the U of A
• Complemented by strong insect evolution group in Ecology & Evolutionary Biology
• Key opportunities in engineering and robotics; agbiosciences insect control and use applications; biomedical research—learning, sensors, disease transmission
• The only neurobiology-of-insects program in the nation
• Could connect more strongly with imaging resources on campus
• World-leading lab on Africanized honeybees (USDA lab)
• Focus on urban and agricultural pest management</td></tr>
</table>

Table B31: Area with Significant Presence: Behavioral Sciences & Community Health

<table>
<tr><th colspan="3">Behavioral Sciences & Community Health</th></tr>
<tr><td colspan="2">Overview</td><td>Behavioral sciences encompass fields such as psychology, social psychology, anthropology and organizational ecology. The goal of research in these areas is to understand the activities of and interactions among individuals and groups. Experiments are designed to investigate decision processes and communication strategies.
Community health studies aim to identify ways to improve the health of people sharing a geographic area or certain characteristics. Education, accessible medical care, and public health datasets are examples of outcomes of community health efforts.</td></tr>
<tr><td colspan="2">Presence in Cluster Analysis</td><td>8 clusters; 185 grants</td></tr>
<tr><td rowspan="3">Competitive Position</td><td>Research Funding</td><td>Federal funding for psychology at U of A in 2003 was $2.6M</td></tr>
<tr><td>Publications Analysis</td><td>Secondary publication strength with 375 papers in Psychology published in 2001-2005; impact relative to field of 1.30</td></tr>
<tr><td>Reputation Standing</td><td>No data</td></tr>
<tr><td colspan="2">Insights from and Niches Identified in Interviews</td><td>• Strong in obesity and weight control and bone health outreach (through the department of nutrition)
• Ties with imaging—functional MRI to investigate depression, stress, etc.
• Ties to College of Nursing in key areas of Risk Reduction in Vulnerable Populations and Managing Consequences of Aging and Chronic Illness</td></tr>
</table>

Table B32: Area with Significant Presence: Cardiovascular Development & Repair

Cardiovascular Development & Repair		
Overview		Cardiology is the branch of medicine concerning the heart and blood vessels. Cardiovascular medicine more broadly concerns the heart and blood vessels as a system in the body. The study of molecular and cellular mechanisms and pathways that play a role in the development of the cardiovascular system and research into the possibility of replacing damaged or dead heart or vascular cells with new cell are the focus of this research area.
Presence in Cluster Analysis		2 clusters; 49 grants
Competitive Position	Research Funding	U of A College of Medicine Dept. of Anatomy and Cell Biology: 18 NIH awards for \$10.8M in FY2005, ranking 17th among U.S. medical schools U of A College of Medicine Dept. of Surgery: 4 NIH awards for \$1.3M in FY2004, ranking 56th among U.S. medical schools
	Publications Analysis	177 papers in Cardiovascular & Respiratory Systems published in 2001-2005; impact relative to field of 1.16
	Reputation Standing	University Medical Center in Tucson ranked 16th nationwide for Heart and Heart Surgery by 2006 *U.S. News & World Report*
	Major Funded Centers or Programs	The FDA granted Tucson-based Critical Path Institute (C-Path) \$675,000 to fund the initial year of a research program to develop "personalized" therapies for patients with cardiovascular disease
Niches Identified in Interviews		• Cardiovascular bioengineering (artificial hearts, cell-based cardiovascular patch, bridge to transplant) and surgery • Cardiovascular development; muscle physiology and development • U of A is known for heart development, muscle research and vascular development • Southern AZ VA hospital strong in cardiology research with translational emphasis; ongoing participation in clinical trials and drug trials • Good track record in bridge to translation/clinical, and bioengineering • Sea squirts as model organisms for beating heart cells • Systems approaches to studying multiple diseases • Muscular Dystrophy Association is HQ'd in Tucson, but stronger involvement with the muscle research groups at U of A has yet to happen • An emerging molecular cardiovascular research program

Table B33: Area with Significant Presence: Basic Physical Sciences

<table>
<tr><th colspan="3">Basic Physical Sciences</th></tr>
<tr><td colspan="2">Overview</td><td>The physical sciences, which together with biological sciences comprise natural science, are generally considered to include astronomy, chemistry, geology, mineralogy, meteorology, and physics.</td></tr>
<tr><td colspan="2">Presence in Cluster Analysis</td><td>N/A</td></tr>
<tr><td rowspan="3">Competitive Position</td><td>Research Funding</td><td>Federal funding for Physical Sciences at the U of A in 2003 was $62.6M; for Chemistry it was $8.2M</td></tr>
<tr><td>Publications Analysis</td><td>157 papers in Chemistry published in 2001-2005; impact relative to field of 1.03</td></tr>
<tr><td>Reputation Standing</td><td>University of Arizona PhD program in Chemistry ranked 38th nationwide by 2006 U.S. News & World Report</td></tr>
<tr><td colspan="2">Insights from and Niches Identified in Interviews</td><td>• Excellent reputation for peptides research
• Strong analytical chemistry track record
• Linked to cancer center for development of novel compounds and drugs
• Linked to pharmacy, neuroscience and insect neuroscience
• Some interactions on valley fever detection, vaccine development, respiratory
• Opportunity for stronger linkage with School of Pharmacy to pursue molecular targeted therapeutics; stronger linkages with plant/agricultural sciences are also needed
• Synthetic organic chemistry is a gap
• Strong crystallography capabilities
• Collaborations with local peptide and protein companies
• U of A Department of Chemistry engaged in the newly formed Arizona Proteomics Consortium</td></tr>
</table>

Table B34: Area with Significant Presence: Bioengineering

<table>
<tr><th colspan="3">Bioengineering</th></tr>
<tr><td colspan="2">Overview</td><td>Also called biosystems engineering or biological engineering, bioengineering is a broad-based field centered on the engineering of biological systems. Objectives range from creating products modeled after biological systems to the modification of biological systems in order to replace or enhance chemical or physical processes.</td></tr>
<tr><td colspan="2">Presence in Cluster Analysis</td><td>N/A</td></tr>
<tr><td rowspan="4">Competitive Position</td><td>Research Funding</td><td>Federal funding for bioengineering/biomedical engineering at U of A in 2003 was $0.8M</td></tr>
<tr><td>Publications Analysis</td><td>No data</td></tr>
<tr><td>Reputation Standing</td><td>U of A School of Biomedical Engineering ranked 30th nationwide for NIH award funding (11 awards for $3.0M in FY2004)</td></tr>
<tr><td>Major Funded Centers or Programs</td><td>Biology, Math and Physics Initiative (IGERT) for graduate student training</td></tr>
<tr><td colspan="2">Insights from and Niches Identified in Interviews</td><td>• Regenerative medicine; stem cells
• Linked with cancer center for development of imaging tools and techniques
• Emerging strength in MEMS and linkages with cancer center for MEMS-related research
• Data transmission and telemedicine programs are very strong; all U.S. patents on robotic telepathology assigned to inventor at U of A
• Local company DMetrix, Inc. is a success story—imaging technology for telepathology and other applications
• Linkages with environmental groups, but not as relates to biorenewables or biofuels
• Strong in signal processing and sensor development</td></tr>
</table>

Table B35: Area with Significant Presence: Applied Math & Biomathematics

Applied Math & Biomathematics		
Overview		Applied math is a discipline concerned with the application of mathematical techniques to other disciplines, such as sciences and technology. Biomathematics focuses on applications in medical science, making contributing to basic research and to the development of specialized computer software that supports health care. Mathematical models are used to represent and study the complex interactions of biological systems.
Presence in Cluster Analysis		N/A
Competitive Position	Research Funding	Federal funding for mathematical sciences at U of A in FY2003 was \$3.1M; for chemistry, \$8.1M; for physics, \$5.5M
	Publications Analysis	No data
	Reputation Standing	University of Arizona Applied Math program ranked 13th nationwide by 2006 *U.S. News & World Report* and 5th by peer institutions
	Major Funded Centers or Programs	The Applied Math program had one of the prestigious, NSF-supported IGERT graduate student training programs, "Multidisciplinary Training in Biology, Math and Physics" from 1998-2005. Now the Biology, Math and Physics Initiative funded by BIO5.
Insights from and Niches Identified in Interviews		• Core strengths in applied mathematics/biomath; peptide chemistry and protein design; biochemistry and structural biology; modeling and mechanics; theoretical math • Unique resources in Department of Chemistry include photoelectron spectroscopy and electroparamagnetic resonance spectroscopy • However, gaps in synthetic organic chemistry; biostatistics • Quantitative Biology Consortium—part of the BIO5 initiative • Linked with bioimaging and biomedical engineering groups • Very strong collaboration with Arizona Cancer Center • Excellent biocomputing group within ARL • Developing linkages with neurosciences and invertebrate neurobiology

Table B36: Emerging Area: Infectious Diseases & Vaccine Development

Infectious Diseases & Vaccine Development		
Overview		Infectious diseases, or communicable diseases, are caused by a biological agent such as a virus, microbe, prion or parasite. Vaccines are preparations that can be either prophylactic or therapeutic and are administered to susceptible populations via any of a number of delivery methods, such as orally or by injection. The development of safe and effective vaccines bridges the gap between basic research and full scale clinical testing.
Presence in Cluster Analysis		2 clusters; 33 grants
Competitive Position	Research Funding	U of A College of Medicine Dept. of Microbiology/Immunology & Virology: 5 NIH awards for $1.5M in FY2005, ranking 83rd among U.S. medical schools
	Publications Analysis	Primary publication strength with 88 papers in Clinical Immunology & Infectious Diseases published in 2001-2005; impact relative to field of 1.31
	Reputation Standing	College of Pharmacy ranked 6th nationwide for NIH award funding in FY 2004 (23 awards for $9.6M)
Niches Identified in Interviews		• Valley Fever Center of Excellence at College of Medicine • Strength in valley fever (coccidiomycosis) research at Southern AZ VA Hospital • Dengue research could be an emerging focus area

Table B37: Emerging Area: Diabetes Research

Diabetes Research		
Overview		Diabetes is a disease characterized by persistently high blood sugar levels. It is a chronic disease that affects at least 171 million people worldwide (World Health Organization). Type I diabetes, also known as insulin-dependent diabetes mellitus, is an autoimmune disease in which the native immune system targets and destroys insulin-producing cells. Treatment involves injection or inhalation of insulin. Type II diabetes, also known as adult-onset or non-insulin-dependent diabetes mellitus, is due to reduced insensitivity to insulin and occurs most frequently in overweight individuals. Treatment generally involves lifestyle changes.
Presence in Cluster Analysis		N/A
Competitive Position	Research Funding	No data
	Publications Analysis	No data
	Reputation Standing	University Medical Center in Tucson ranked 39th nationwide for Kidney Disease by 2006 *U.S. News & World Report*
Insights from and Niches Identified in Interviews		• Two new hires for diabetes research at the University of Arizona • Linked to nutrition department • U of A strengths in obesity and weight control • Ties to College of Nursing, which is building a major diabetes research program • Federal funding for Arizona diabetes center of excellence through the U of A telemedicine program

SUMMARY

The above tables provide insight into the bioscience areas of focus and core competencies within Southern Arizona. Conclusions regarding these strengths and competencies are incorporated, together with the findings of the quantitative analysis, to develop and refine "technology platforms" upon which a bioscience economy may be built. The recommended platforms and the research core competencies to leverage in building them are discussed in detail in the following section.

Technology Platforms, Products and Market Niches for Southern Arizona

Background on Technology Platforms

The purpose of identifying a region's research strengths and core competencies is to be able to identify strategic areas of focus that offer the greatest opportunity for near term development—Battelle uses the term "technology platforms" to describe these.

Technology platforms serve as a bridge between research core competencies and their use in commercial applications and products. As such, platforms are highly translational in nature—working to facilitate strong directional movement of ideas and innovations from basic science discoveries through to applied technologies and practices.

The technology platform process can be understood through a systems approach in which innovations flow from core competencies resident in a region's research institutions, via the platforms, to commercial products, which then find their way into markets. These technology platforms are intended to be robust and evergreen and to integrate several of the core competencies to produce a continuous flow of innovative, and perhaps disruptive, technology or products. Platforms also serve as a forum for building strong interactions and relationships between academic researchers and their counterparts in industry.

The areas of greatest opportunity for developing technology platforms are those in which a region has:

- Existing research strengths
- Bases of commercial activity emerging or established within the region with genuine opportunity to create a base in the near future
- Distinct opportunities to leverage the region's comparative advantages to create competitive marketplace advantages
- Significant product market potential
- Links to, or reinforcements of, other bioscience strengths and core research competencies, thereby helping to enhance other fields as a platform expands.

The Arizona Statewide Technology Platforms

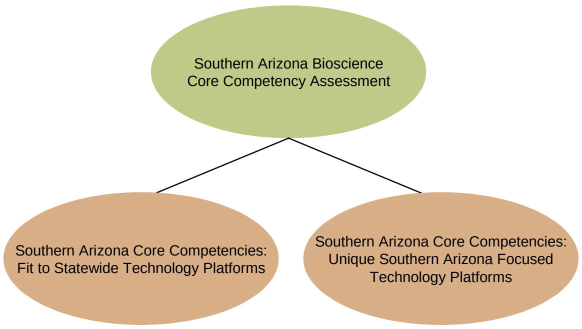
Previous work by Battelle for the Flinn Foundation has identified Arizona statewide bioscience technology platforms, and much progress has been made in advancing development in the state along these platform pathways (Table B38).

Table B38: Statewide technology platforms identified in prior Battelle work

Near-Term Platforms	Mid-Term Platforms	Cross-Cutting Platforms
• Cancer • Neurosciences • Bioengineering •	• Asthma • BioAgriculture • Infectious Diseases • Diabetes	• Bioimaging • Translational • Tissue

Of these, the team identified core competencies and associated platforms that are uniquely Southern Arizona focused as well as areas where Southern Arizona core competencies contribute to statewide platforms (Figure B7).

Figure B7: Southern Arizona Technology Platforms Derived from Core Competencies



Analysis of the bioscience R&D core competencies at southern Arizona research institutions shows that the southern Arizona region plays a leading or important contributory role in each of the ten statewide technology platforms. Southern Arizona, strongly centered on the work of the University of Arizona, plays a key driver role in the “cancer”, “bioengineering”, “neurosciences”, “asthma”, and “bioagriculture” technology platforms, and is also the key driver of work in the cross-cutting “bioimaging” platform. The region also has a strong contributory role to play in “infectious diseases” and “diabetes”, together with the cross-cutting “translational” and “tissue” platforms (Figure B8).

Given that Tucson is home to the University of Arizona, the state land-grant university (and thus home to bioagricultural R&D), and the home to the only allopathic medical college for the state, it is understandable and expected that southern Arizona’s bioscience platform focus areas should be a close match to statewide focus areas. This, indeed, is what is found—although some additional distinctive areas of research focus, deserving of southern Arizona platform status, are also evident.

Figure B8: Southern Arizona Crosswalk to Original Statewide Roadmap Platforms

- Statewide AZ Biosciences Roadmap platforms:
  - **Near Term**
    - Cancer (Therapeutics) → Southern Arizona Key Driver
    - Bioengineering → Southern Arizona Key Driver
    - Neurosciences → Southern Arizona Key Driver
  - **Mid Term**
    - Asthma → Southern Arizona Key Driver
    - Bioagriculture → Southern Arizona Key Driver
    - Infectious Diseases → Southern Arizona Contributor
    - Diabetes → Southern Arizona Contributor
  - **Cross Cutting**
    - Bioimaging → Southern Arizona Key Driver
    - Translational → Southern Arizona Contributor
    - Tissue → Southern Arizona Contributor

With Southern Arizona holding such a strong position in driving forward Arizona’s ambitions for technology-based economic development from biosciences it is clear that the region should have multiple opportunities for local economic development centered on its research core competencies.

Translating Southern Arizona Core Competencies into Technology Platforms

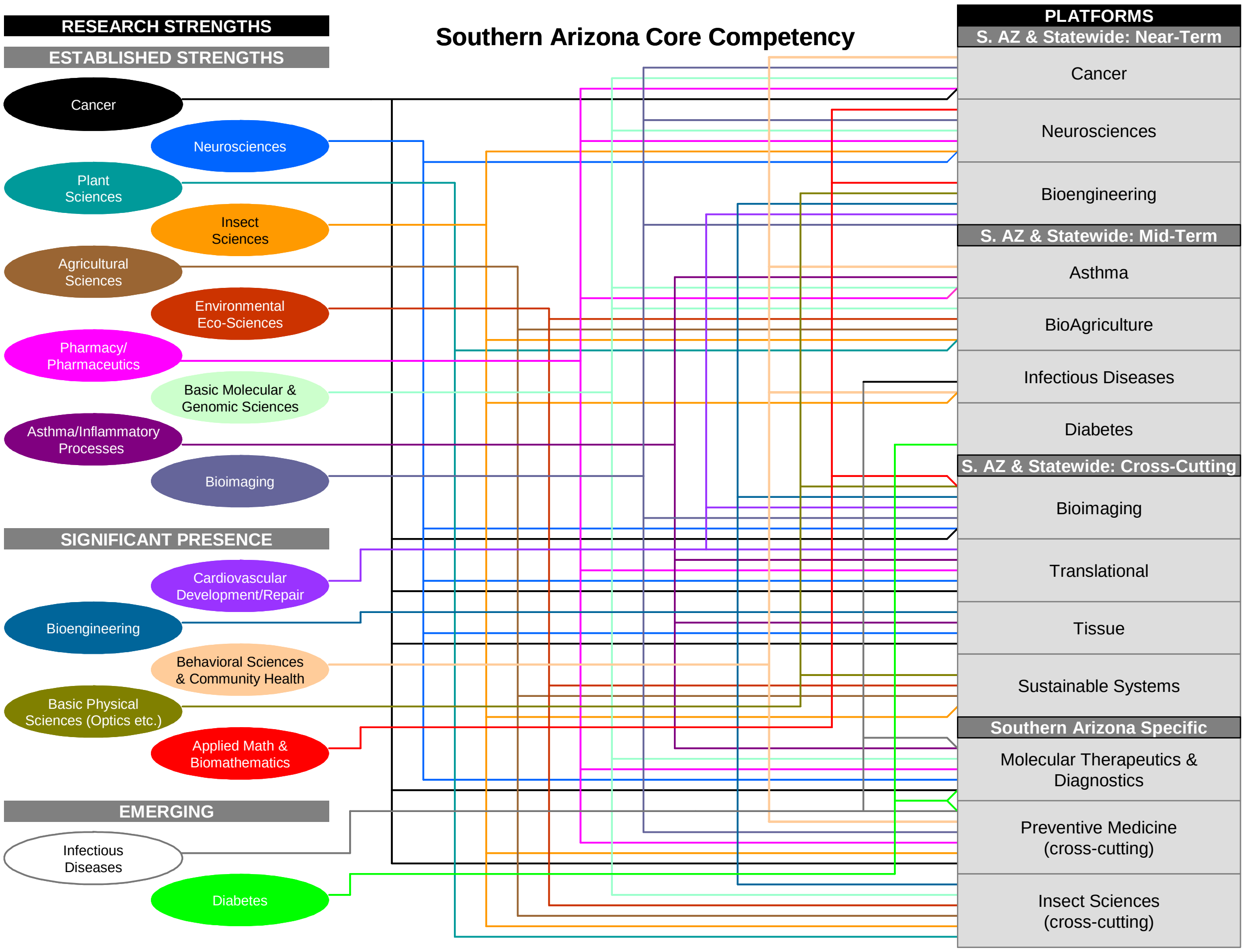
As previous chapters show, southern Arizona is a base for a broad range of bioscience R&D core competencies. These core competencies are summarized in Table B39, segmented into “established strength”, “significant presence” and “emerging” core competencies.

Table B39: Southern Arizona Research Core Competencies

Established Strengths	Areas with Significant Presence	Emerging
• Cancer Research • Neurosciences • Plant Sciences • Basic Molecular & Genomic Sciences • Agricultural Sciences • Insect Sciences • Environmental Eco-Sciences • Pharmacy/Pharmaceutics • Bio-Imaging • Asthma & Inflammatory Processes	• Cardiovascular Development/ Repair • Bioengineering • Basic Physical Sciences • Applied Math & Biomathematics • Behavioral Sciences & Community Health	• Diabetes Research • Infectious Diseases & Vaccine Development

Translating R&D strengths into platforms requires understanding the cross-disciplinary relationships and connections that exist upon which broad-based platforms can be built. Figure B9 shows the sheer complexity of the interrelationships between each R&D core competency and the individual statewide and southern Arizona-centric platforms.

Figure B9: Relationship between Southern Arizona Research Core Competencies and Statewide/Southern Arizona Technology Platforms



In addition to those Southern Arizona core competencies that link directly to the ten existing statewide technology platforms, core competencies also link to three Southern Arizona-specific technology platforms comprising:

- Molecular Therapeutics
- Preventive Medicine
- Insect Sciences.

These represent platforms where most (but not all) Arizona activity is strongly focused within the University of Arizona, and which present excellent opportunities for technology-based economic development to occur in the Tucson region.

The technology platforms represent the base from which a significant R&D, business base, and bioscience economy may be built. They each specifically draw upon the Southern Arizona region's institutional expertise in multiple fields, since it is multidisciplinary research that is increasingly gaining importance in driving new study areas, technologies, and commercializable innovations and discoveries. The assembly of multidisciplinary platforms is also likely to increase the opportunity for winning federal agency grant awards.

Figure B9 shows how the Southern Arizona region's bioscience research strengths, determined through both quantitative and qualitative analyses, lead to the recommended technology platforms. Each of the platforms is discussed in following narratives, starting with the Southern-Arizona specific platforms. Each narrative includes a figure designed to show the specific linkages between the quantitatively based and qualitatively based core competency disciplines and recommended platforms and opportunity areas. The figures graphically illustrate the way in which these platforms are reinforced by the R&D talent across a wide range of strength disciplines in Southern Arizona.

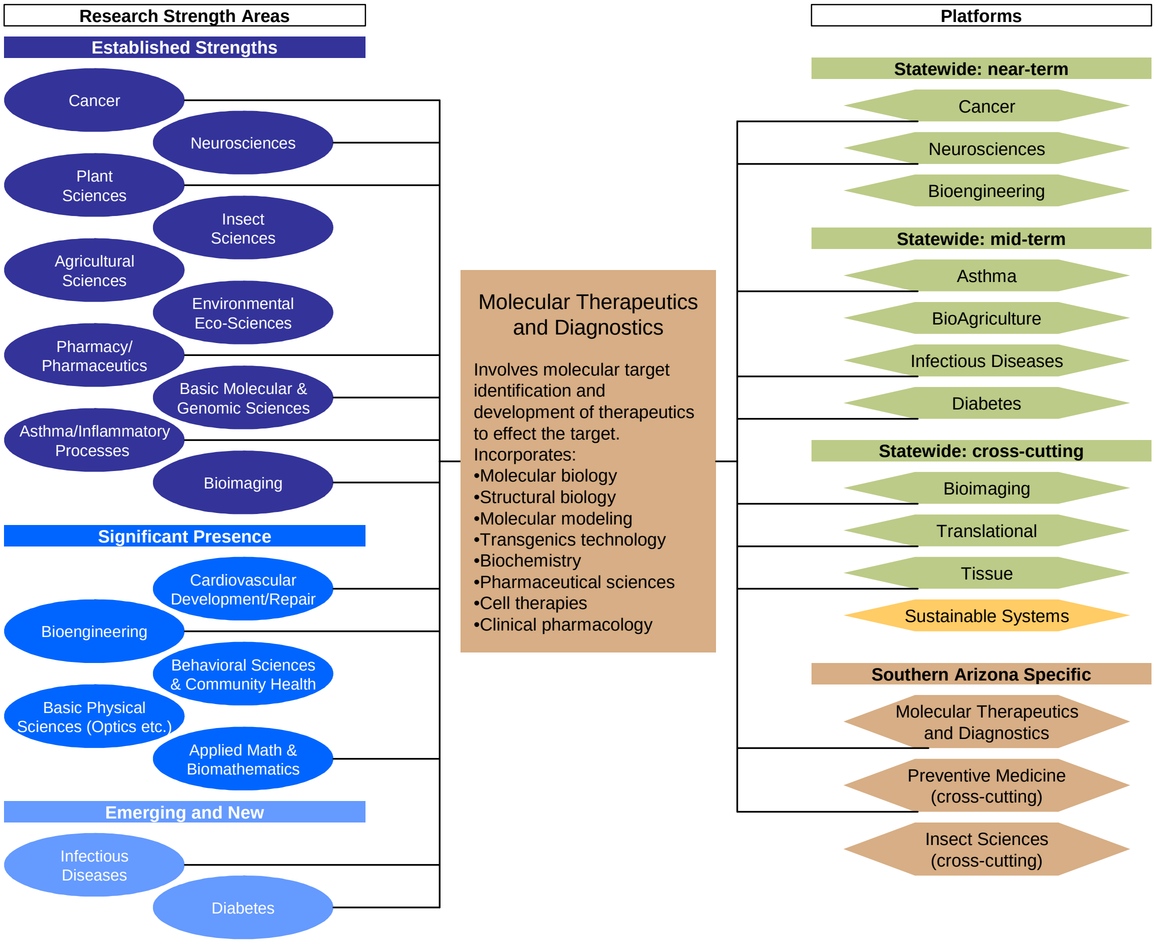
OVERVIEW OF SOUTHERN ARIZONA-SPECIFIC PLATFORMS

Molecular Targeted Therapeutics and Diagnostics

Modern post-genomic sciences provide U of A with the ability to progress the development of disease diagnostics and therapeutics through identification of specific molecular targets. The Arizona Cancer Center has been at the forefront of molecular target identification and has extended this expertise into the discovery and development of novel anti-cancer therapeutics designed to positively impact the identified molecular targets. Building from the strong work in cancer at U of A multiple groups are coming together to drive the concept of a molecular targeted therapeutics and diagnostics focus forward—including the Arizona Cancer Center, BIO5 initiative, College of Pharmacy and Department of Chemistry.

While cancer is an important initial focus of expertise for southern Arizona in molecular targeted therapeutics, there is also an emerging push towards extending this expertise into molecular therapeutics discovery and development for neurological therapeutics applications. The formation of a dedicated platform in molecular targeted therapeutics in Tucson is supported by progress already made by U of A faculty in developing technologies and companies to commercialize these technologies (Figure B10). Key product opportunities will present themselves in the form of both molecular diagnostic tools and tests, and drugs and other therapeutic agents.

Figure B10: Molecular Therapeutics and Diagnostics Platform (Southern Arizona-specific)



Within Arizona the only molecular targeted therapeutics program is at the University of Arizona. By building upon this U of A program, Arizona will benefit statewide in its bioscience initiatives since targets for therapeutics have the potential to be identified within multiple research institutions in the state (such as T-Gen, Barrows, ASU, etc.). Currently, while there has been great investment in Arizona in defining disease at the molecular level, which can then be translated into molecular biomarkers, the next-step towards producing therapeutics to impact these targets has not been the subject of investment. The University of Arizona clearly has the basic elements required to drive development of a significant platform presence in the discovery and development of molecularly targeted drugs—by building upon this foundation further, Arizona will be far better positioned to capitalize on its growing base of identified molecular markers.

As envisioned by leaders in this field at U of A, a campus-wide program in molecular targeted therapeutics would interface with molecular diagnostics and imaging to form a platform that would greatly facilitate the progress of clinical translational programs in Arizona. The physical infrastructure for ramping-up molecular targeted therapeutics is nearing completion at the University, with Bio5, the Chemistry Department and the new Medical Research Building having dedicated significant space to developing this platform.

There are gaps and additional investment requirements that will need to be addressed to achieve the rapid platform development that southern Arizona could see in this arena. U of A will need funds to recruit a recognized program director for drug discovery and development together with several key faculty hires to reinforce complementary areas including medicinal chemistry, synthetic organic chemistry and clinical pharmacology. Phase I trials support services and staffing will also need to be addressed. Additional investment will also be required in support of boosting training programs and fellowships in drug discovery and development at U of A.

Investing in a molecular targeted therapeutics platform for southern Arizona will leverage the existing expertise in this area coming out of cancer, help capitalize further on the considerable new space coming on stream in support of therapeutics discovery and development at the university, and provide a natural pathway for translating the understanding of disease at the molecular level that is the focus of so many Arizona bioscience research institutions.

Preventive Medicine

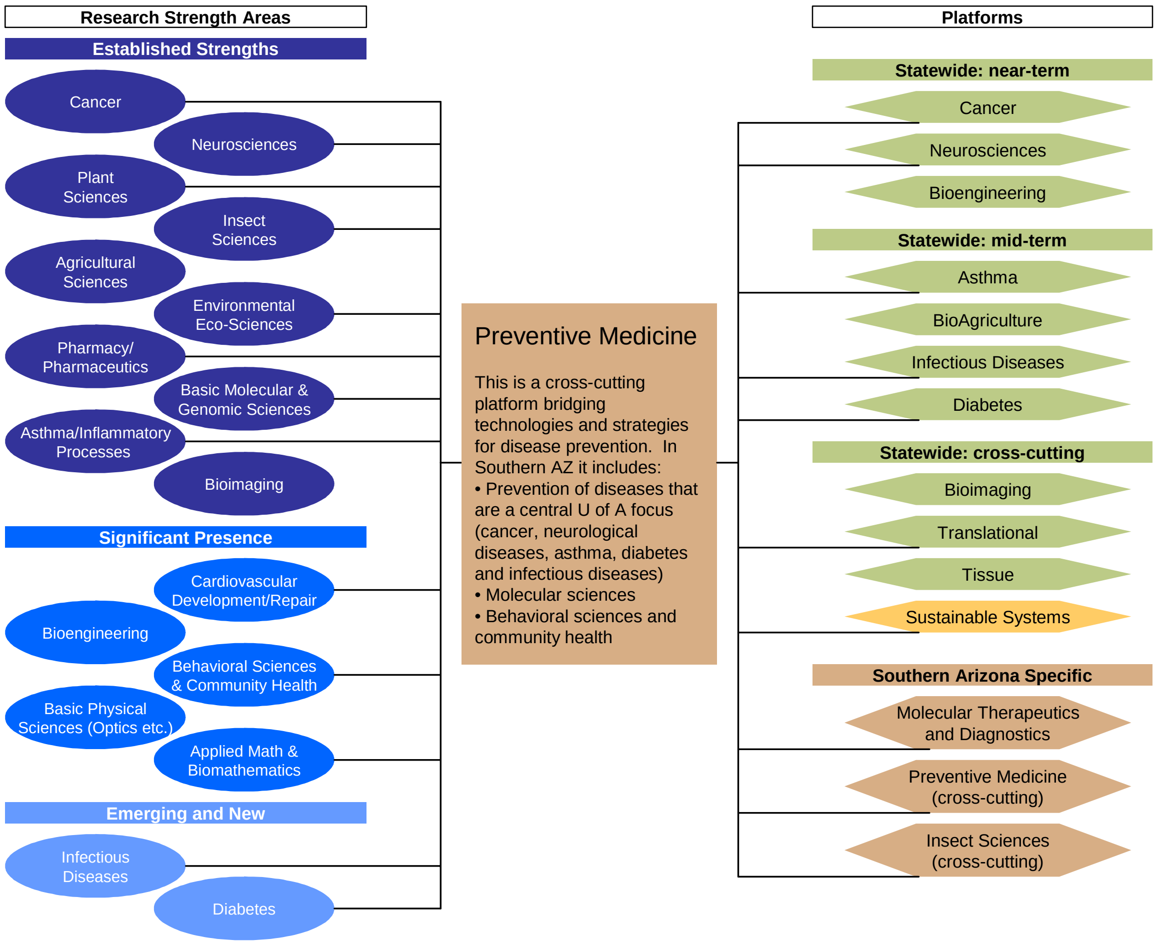
Preventive medicine is the branch of research and practice which aims at the prevention of disease and the promotion of health. Through epidemiologic analysis, genomic analysis, phenotype analysis, and the tools of public health, preventive medicine is “coming of age” and providing deeper understanding of pathways to disease prevention. As the field progresses and expands there will be widespread application for the translation of R&D discoveries into commercializable strategies, products and technologies.

In southern Arizona expertise extends from epidemiology and public health analysis, through to genomic and molecular studies that may lead to personalized-medicine approaches to preventive medicine. A preventive medicine platform has the potential to bring together a highly diverse, interdisciplinary group of high-profile researchers conducting work in behavioral sciences and community health, basic molecular and genomic sciences, plant and natural products, and specific disease focus areas (Figure B11). Southern Arizona is quite uniquely positioned to bring multiple pathways of discovery together to produce novel strategies and products. The region is also well-positioned for taking holistic approaches to disease prevention that take into account environmental factors, sociological factors, and genetics.

Southern Arizona has the opportunity to build its early preventive medicine work around the cancer focus area. The Arizona Cancer Center at the College of Medicine is the leading research funding recipient for federal dollars directed at cancer prevention and control, and forms the basis for further expansion in this area.

From a product pathway standpoint, there will be demand for the development of preventive agents, such as chemopreventive agents in cancer—agents targeting genetic, molecular, phenotypic, biochemical and immunologic markers. Similar opportunities will be afforded in other biomedical focus areas for southern Arizona around neurological and neurodegenerative diseases, respiratory disorders and diabetes. Furthermore, commercial opportunities will likewise be presented in diagnostic tools and technologies and in analytical techniques and technologies. Work in infectious disease prevention and vaccine technologies will also be a natural fit with this platform.

Figure B11: Preventive Medicine Platform (Southern Arizona-specific)

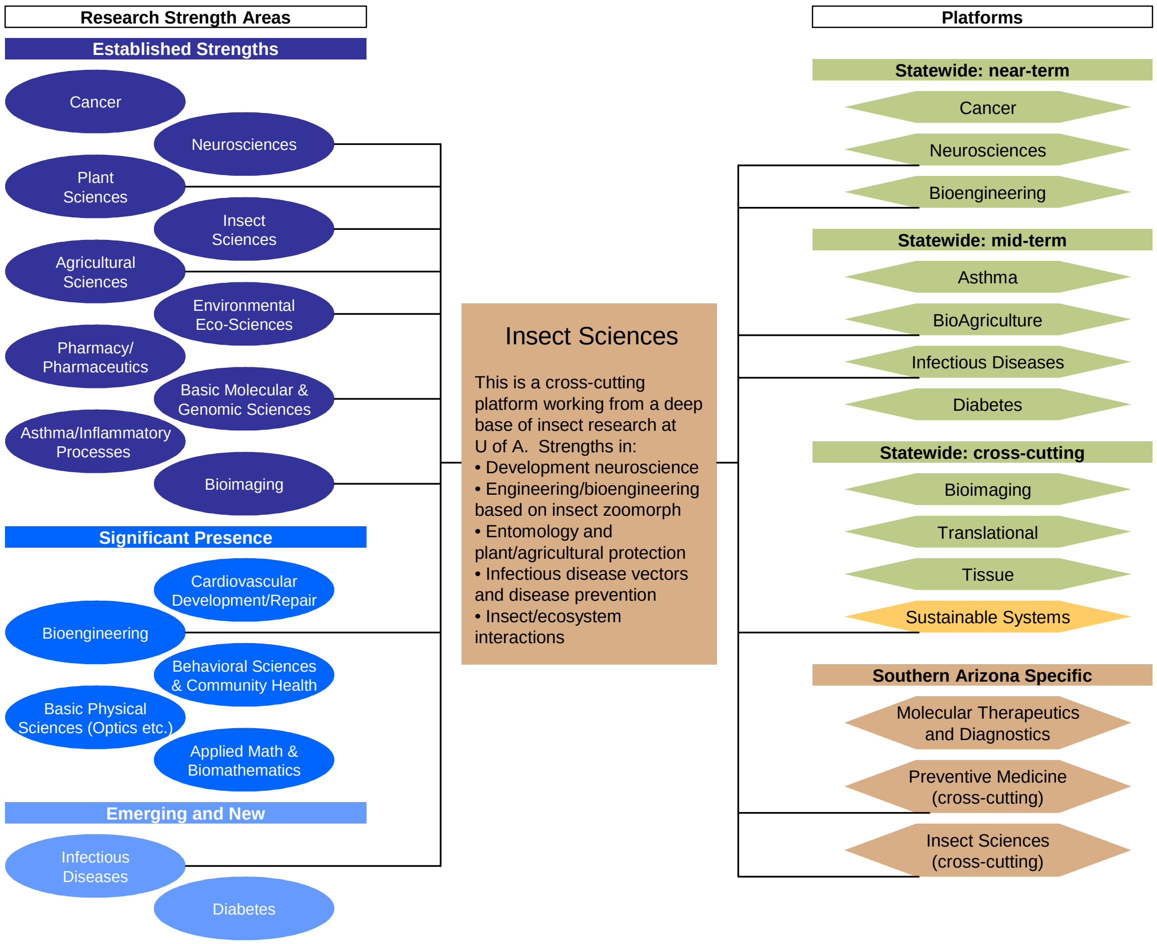


Insect Sciences

The University of Arizona is home to the Center for Insect Sciences (CIS), an operating division under the Arizona Research Laboratories. CIS is probably the world's leading collaborative center for interdisciplinary research using insects, and currently contains more than 130 faculty members drawn from across 15 departments. The center also benefits from having collaborators from both Arizona State University and Northern Arizona University, but by far the main cluster of scientists is within U of A.

As a platform, insect sciences is best viewed as "cross-cutting" because its applications and areas of study are quite broad and applicable to supporting advancement in a broad range of other Arizona and Southern Arizona bioscience platforms (Figure B12). The diversity of faculty engaged in CIS R&D points to the multi-disciplinary nature of the platform with participants drawn from electrical and computer engineering; mechanical engineering; aeronautical engineering; human physiology; neuroscience; molecular, cellular, and developmental biology; evolutionary biology and ecology, as well as the more traditional entomological sciences.

Figure B12: Insect Sciences Platform (Southern Arizona-specific)



Applications for CIS cross-disciplinary expertise are also multi-dimensional, including opportunities in:

- **Engineered Products**—This includes products using insect models, insect-based structures, or insect-based biomaterials to produce novel devices, prostheses and biomaterials for biomedical and non-biomedical applications. Faculty within the insect sciences program are already moving along the engineered products pathway with initiatives in: neuromorphic engineering of visual prosthetics; development of visually intelligent autonomous robots; and optics design for bioimaging applications.
- **Agricultural and the Environment**—This includes products and solutions to agricultural pest control, together with control methods and technologies for endemic urban/household insect pests. In addition, insect sciences expertise can be leveraged to investigate plant-insect interactions in relation to pollination and agricultural challenges peculiar to Southwest agricultural and natural ecosystems. There is also considerable potential for development of insects as sensors for use in climate change and genetic drift environmental monitoring applications.
- **Infectious Disease Vectors**—This includes technologies and solutions targeting insect hosts for zoonotic infectious diseases. Here there is a cross-link to the preventive medicine platform.
- **Expansion in Basic Sciences and Biomedical Research—** In both basic and plied research areas there is great potential for using insects as model organisms for advancements in developmental

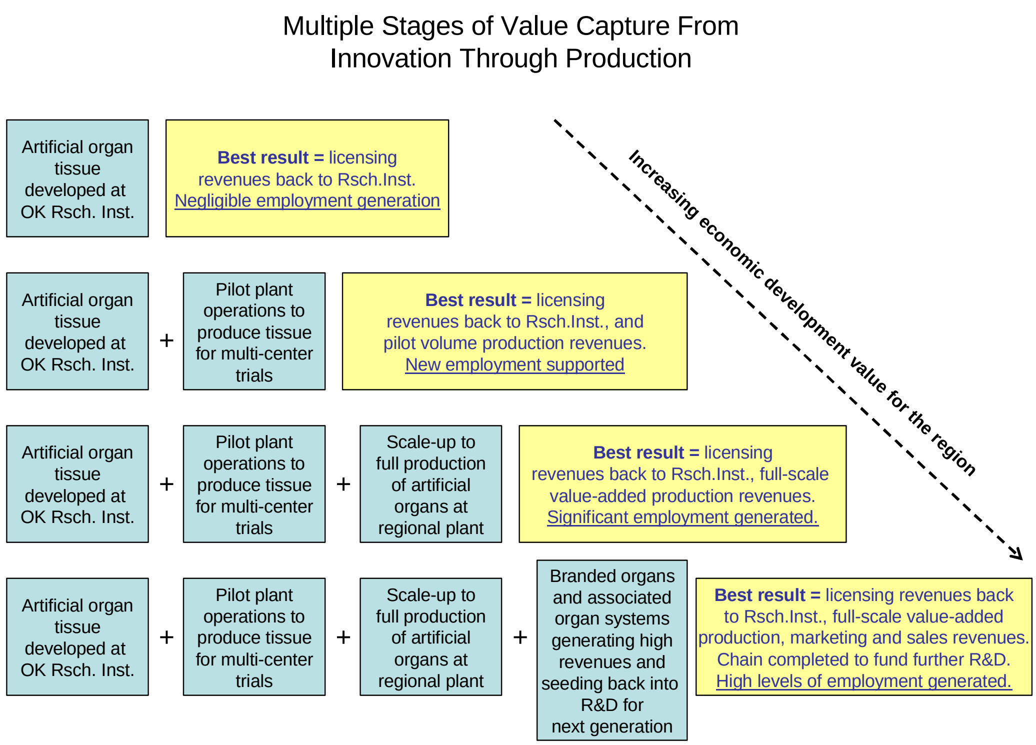
biology, evolutionary biology, neurobiology and other related bioscience disciplines. Some of the specific areas of application being advanced at U of A include: genetic screening for cerebral defects; models of muscle innervation and neurodegenerative disease; mechanisms of sensory perception; models for learning, memory and aging; and Alzheimer's disease models.

Through platform status, the deep insect sciences expertise in southern Arizona can be directed towards specific focused projects—both in terms of technologies from the insect sciences platform itself, and in terms of support to advancements in other platforms such as neurosciences, bioengineering, bioagriculture and infectious diseases

MARKET ANALYSIS

The ultimate goal for the southern Arizona region in supporting the development of bioscience platforms is economic development. R&D, in and of itself, ***is*** economic development in that millions of dollars flow into the region each year from federal and other external funding sources to support research. These dollars, in turn, create jobs and income for persons in the Tucson area in, and related to, the R&D sector. **The goal of technology-based economic development, however, is to move into an integrated model whereby local research feeds a local commercialization and production cluster, thereby capturing increased value-added economic gains for the region from its R&D work.** Figure B13 shows the increasing returns to commercial development of bioscience R&D into full-scale production of bioproducts.

Figure B13: Increasing Economic Returns through Production of Bioproducts



Given the increasing regional economic returns through the commercialization of R&D innovations it is highly important that the development of platforms be made with an eye to markets and commercialize-tion opportunities related to each platform. Tables B40 through B50 show how R&D core competencies are linked to applications, potential products and general market characteristics. It is evident that each of the platform focus areas addresses multi-billion dollar markets, providing considerable opportunity for growing the regional bioscience economy around these core competencies.

Table B40: Molecular Therapeutics and Diagnostics Platform (Southern Arizona-specific) Development Pathway

Basic Research	• Molecular biology • Structural biology • Molecular modeling • Biochemistry and signaling
Enabling Technology	• Pharmaceutical science • Clinical pharmacology • Structural and functional imaging • Small mammal transgenics
Technology Platform	Molecular Therapeutics and Diagnostics
Applications and Products	• Molecular diagnostic tools • Molecular therapeutics (drugs)
Markets	• The global market for prescription drugs is predicted to grow between 6–7% in 2006 to a total size of $640-650 billion (IMS Health). The U.S. market represents fully 43% of global pharmaceutical sales, and is expected to grow faster at between 8–9%. • Cancer drug sales (an area in which southern Arizona has considerable strengths) are projected to reach $55 billion in 2009, compared to the $24 billion in 2004 (IMS Health). • By 2009, the top drug categories are projected to be: (IMS Health) 1. Oncology ($55 billion) 2. Cholesterol $38 billion 3. Antidepressants ($26 billion) 4. Stomach ulcer treatments ($26 billion) 5. Hypertension drugs ($24 billion) 6. Antipsychotics ($20 billion) 7. Platelet inhibitors ($18 billion) 8. Anemia drugs ($18 billion) 9. Osteoporosis ($16 billion) 10. Anti-epileptics ($15 billion). • Molecular diagnostics markets overlap with markets for non-molecular diagnostic technologies in the in vitro diagnostic market and are less well defined than those for pharmaceuticals. In the year 2005, the global market for molecular diagnostics was worth $6.5 billion, representing approximately 3.3% of the total diagnostics market and approximately 14% of the in vitro diagnostic market (Jain PharmaBiotech 2006). • The molecular diagnostics market will expand to $12 billion by 2010 and $35 billion by 2015. A major portion of it can be attributed to advances in genomics and proteomics. Biochip and nanobiotechnology are expected to make a significant contribution to the growth of molecular diagnostics (Jain PharmaBiotech 2006).

Table B41: Preventive Medicine Platform (Southern Arizona-specific) Development Pathway

Basic Research	• Genetics and genomics • Molecular biology • Immunology • Epidemiology • Public health • Biostatistics, mathematics and modeling
Enabling Technology	• Rapid genetic testing • Bioimaging • Animal research facilities • Pharmaceutical science • Clinical pharmacology
Technology Platform	Preventive Medicine
Applications and Products	• Diagnostics • Preventive drug therapies • Gene and cellular therapies • Vaccines • Personalized medicine clinical services • Public health analytical tools and technologies
Markets	• Preventive medicine, from a product perspective, will include a broad range of clinical diagnostics, genetic tests, drug therapies and non-drug therapeutics (e.g. cellular transplantation, gene therapy). Preventive diagnostics and therapeutics represent an extremely large market opportunity, since preventative steps may be applicable to almost every person. Since the global market just for current prescription drugs is approximately $650 billion, it is likely that preventive drugs and diagnostics could quite rapidly become $100 billion+ markets. The potential market for personalized clinical preventive care will also be very large, and represent a sub-regional opportunity since much care, counseling and related analytical services will be provided locally. • The more individually focused, personalized approaches contained in targeted preventive medicine will likely favor smaller niche companies, producing custom products (as opposed to major pharmaceutical companies with blockbuster drugs). Thus the business development opportunities, and associated localized economic impacts, are likely quite high for preventive medicine. • Vaccines are also a preventive medicine component. The vaccine market represents a significant growth opportunity. Industry estimates vary but Merrill Lynch suggests the worldwide market could be worth $10 billion by 2006. Much of the predicted growth of the vaccines market is expected to come from the introduction of new vaccines, either against diseases for which no vaccine currently exists or as second-generation products to replace existing vaccines.

Table B42: Insect Sciences Platform (Southern Arizona-specific) Development Pathway

Basic Research	• Entomology • Developmental neurobiology • Structural biology • Comparative anatomy • Engineering disciplines • Chemistry and chemical engineering
Enabling Technology	• Structural and functional imaging • Insect breeding facilities • Engineering facilities
Technology Platform	Insect Sciences
Applications and Products	• Insect-inspired engineered materials • Insect-inspired engineered systems • Insect-based materials • Agricultural and urban pest control products
Markets	• Many of the potential products that could result from insect science discoveries are very difficult to attach market figures to. • In terms of "green" materials, the global market was estimated to stand at $6.1 billion in 2005, and is expected to reach $8.7 billion by 2010—an average annual growth rate of 7.4% (electonics.ca publications). • Nanomaterials, as an example of an emerging materials market, accounted for $9.4 billion in 2005 and over $10.5 billion in 2006, growing to about $25.2 billion by 2011— an average annual growth of 19.1% between 2006 and 2011 (electonics.ca publications). • Smart materials, another emerging materials category, have also built up markets quite rapidly. The worldwide smart materials market is estimated at $8.1 billion in 2005 and is expected to rise at an average annual growth rate of 8.6% to $12.3 billion in 2010 (electonics.ca publications). • Chemicals for insect control (insecticides) comprise a substantial global market. In 2000 the global insecticide market was estimated at $8.7 billion, with the U.S. comprising $3.1 billion. The $3.1 billion in insecticides sold in the U.S. are split quite evenly between those used for agricultural applications and those used in home and garden applications (U.S. EPA).

Table B43: Cancer Research Platform (Statewide Near-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Molecular biology • Cell biology • Cancer immunology • GI cancers • Skin cancer
Enabling Technology	• Imaging • Clinical pharmacology • Genomics and proteomics • Animal research facilities
Technology Platform	Cancer
Applications and Products	• Drugs • Biologics • Diagnostics • Clinical care volume
Markets	• The market for cancer treatments in the United States is currently $1.65 billion and is growing by 10% per annum. • The oncology treatment sector is worth an estimated $35 billion worldwide (2004), and Datamonitor projects this to grow to $60 billion by 2008, yielding a compound annual growth rate of 8% over this period • In 2004, the top 20 cancer drugs in each of the seven major pharmaceutical markets generated combined sales exceeding $27 billion. • The American Cancer Society tracks new cancer cases on an annual basis and shows that in 2004 almost 1.4 million new cases of cancer occurred in Americans • A point in time estimate conducted by the National Cancer Institute in 2000 calculated that 9.6 million Americans had diagnosed cancer(s) at that time • WHO reported in 2000 that global cancer rates are expected to increase 50 percent by the year 2020. Over 22 million people in the world were treated for cancer in 2000.

Table B44: Neuroscience Platform (Statewide Near-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Neurology • Neuroscience • Psychiatry • Developmental neurobiology • Molecular biology
Enabling Technology	• Pharmaceutical science • Clinical pharmacology • Structural and functional imaging • Sensors • Transgenic mouse technology
Technology Platform	Neuroscience
Applications and Products	• Non-psychiatric neuro-therapeutic drugs (treatments for pain, MS, Parkinson's, Alzheimer's, etc.) • Psychiatric drugs • Diagnostic tools • Clinical care volume
Markets	• Changing demographic factors are expected to result in increased numbers of people requiring treatment for Parkinson's disease, neuropathic pain and other pain syndromes, and for Alzheimer's disease because these disorders are more prevalent in elderly people. • The world market for non-psychiatric neurotherapeutics stood at $70 billion in 2002, according to the study, but steady growth in demand and product introduction will result in markets in excess of $88 billion by 2010. (source: Kalorama Information) • While neurological cancer presents the largest defined segment of neurotherapeutics at the moment, the largest area of opportunity is that for peripheral neuropathies. The market potential for pharmaceuticals in the treatment of peripheral neuropathies represents $15 billion in the seven major world healthcare markets. This market potential is growing at the compound annual rate of 6.3%. • Large-scale opportunities for both psychiatric and non-psychiatric neurotherapeutics. Non-psych applications include: disease, amyotrophic lateral sclerosis, brain and spinal cord injury, cognition disorders, epilepsy, insomnia, multiple sclerosis, neurological cancers, Parkinson's disease, peripheral neuropathy, neuropathic pain, and stroke. • The worldwide market for drugs for the treatment of Parkinson's disease alone was more than $2.0 billion in 2004. • The worldwide market for neuropathic pain drugs was estimated at more than $3 billion in 2004 and is projected to grow rapidly, with sales in 2010 reaching $10 billion. The total worldwide market for all pain drugs was estimated at more than $30 billion in 2004 and is projected to continue growing at a rate of about 10% per year. • The worldwide drug market for Alzheimer's disease was estimated at nearly $2 billion in 2004. Rapid growth is projected. (Source: Cita Neuro Pharmaceuticals)

Table B45: Bioengineering Platform (Statewide Near-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Molecular and cellular biology • Structural biology • Developmental biology • Materials science and engineering
Enabling Technology	• Imaging • Tissue engineering • Materials fabrication • Prototyping facilities
Technology Platform	Bioengineering
Applications and Products	• Engineered tissue and organ systems • Biomaterials and bio-compatible materials • Implantable medical devices • Non invasive biomedical devices and instrumentation • Drug and therapeutics delivery systems • Sensors, nanotechnology and MEMS materials and devices
Markets	• The current world market for replacement organ therapies is in excess of $350 billion, and the projected U.S. market for regenerative medicine is estimated at $100 billion. (Source: U.S. Dept. of Health and Human Services) • Biocompatible materials used in implantable medical devices currently comprise a $1 billion market. While the implantable device market itself is a global $50 billion industry. Current major materials, including medical-grade polymers, metals, advanced ceramics, pyrolytic carbon, composites, and natural materials. End-use devices include implants, valves, grafts, pacemakers, bone repair and replacement devices, artificial organs, dental materials, drug-delivery systems, dialysis/separation/filtration systems, and catheters and stents. (Source: BCC Research). • Nanomaterials accounted for $9.4 billion in 2005 and over $10.5 billion in 2006, growing to about $25.2 billion by 2011—an AAGR of 19.1% between 2006 and 2011. (Source: electonics.ca publications). • Fuji-Keizei USA specifically examined the biosensor market and estimates that the market size for worldwide biosensors at year end 2003 was about $7.3 billion. They project a growth rate of 10.4% to $10.8 billion in 2007.

Table B46: Asthma Research Platform (Statewide Mid-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Molecular biology • Cell biology • Immunology • Respiratory sciences
Enabling Technology	• Pharmaceutical science • Clinical pharmacology • Structural and functional imaging • Transgenic mouse technology
Technology Platform	Asthma
Applications and Products	• Drugs • Biologics • Diagnostics
Markets	• The asthma treatment market is a $15 billion market, driven by an increasing prevalence and yet without a treatment to cure this debilitating disease. All current drugs treat the symptoms but not the underlying cause. (Source: Visiongain) • Asthma affects between 100 and 150 million people worldwide. Asthma cases doubled and even quadrupled in some countries in Western Europe since the 1970s. The worldwide asthma therapeutics market was estimated at over $12.92 billion in 2005 and is expected to grow at a compound annual rate of 11.2% to reach more than $21.94 billion by 2010. U.S. respiratory drug costs are currently around $14 billion, Japan spends more than $3 billion and the bill in each of the top five European countries exceeds $1 billion per annum. The U.S. grew by 21% in the last year fueled by new drug development and disease awareness campaign. (Source: Amar Enhsaihan, Kelley School of Business, Indiana University) • The over the counter (OTC) allergy and asthma market is currently the largest OTC segment in the United States, with sales surpassing $1.7 billion last year. (Source: Kalorama)

Table B47: Bioagriculture Research Platform (Statewide Mid-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Plant biology • Molecular and cellular biology • Biochemistry • Genetics • Pharmacy
Enabling Technology	• Genomics, proteomics • Plant Transformation/Transgenics • Controlled growth environments • Pharmaceutical sciences
Technology Platform	Bioagriculture
Applications and Products	• Improved crop plants • Transgenic plants • Functional foods and nutraceuticals • Plant produced pharmaceuticals and chemicals
Markets	• The worldwide market for agricultural biotechnology currently stands at approximately $2.2 billion. (Source: Bharat Research) • World demand for transgenic seeds will grow 12 percent annually through 2006. The U.S., Argentina, Canada and China will continue to dominate transgenic crop cultivation. Genetically modified (GM) soybeans, corn and cotton will remain the leading seeds, with GM rice to be introduced in 2003 and expected to reach U.S. $1.3 billion in sales by 2011. (Source: Bharat Research) • In 2003, the global market value of GM crops is estimated to be $4.50 to $4.75 billion, having increased from $4.0 billion in 2002 when it represented 15% of the $31 billion global crop protection market and 13% of the $30 billion global commercial seed market. The market value of the global transgenic crop market is based on the sale price of transgenic seed plus any technology fees that apply. The global value of the GM crop market is projected at $5 billion or more, for 2005. (Source: International Service for the Acquisition of Agri-biotech Applications) • Biomass for energy applications is likely to grow considerably as a response to unstable international oil prices. According to Frost & Sullivan Research, demand for biomass energy, raw materials and services exceeded $3.4 billion in 2005. • In 2003 biomass was the leading source of renewable energy in the United States, providing 2.9 Quadrillion Btu of energy. Biomass was the source for 47% of all renewable energy or 4% of the total energy produced in the United States. (Source: U.S. Dept. of Energy) • BioPharming (the production of drugs via plant pathways) is expected, within the next 8 years, to have significantly impacted production of therapeutic biologics in development and on the market. Over this time period, BioPharming is expected to grow into a $100 billion to $125 billion production industry. Newer developments made possible by biopharming may be responsible for a further 15% expansion of the market to $140 billion in 2010. (Source: Theta Reports)

Table B48: Infectious Diseases Research Platform (Statewide Mid-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Microbiology • Molecular biology • Cellular biology • Cellular immunology • Molecular genetics and immuno-genetics
Enabling Technology	• Clinical pharmacology • Genomics and proteomics • Bioinformatics • Animal facilities • Imaging
Technology Platform	Infectious Diseases
Applications and Products	• Drugs • Biologics • Diagnostics • Vaccines
Markets	• In the United States two of the ten leading causes of death are infectious diseases (HIV and pneumonia/influenza). The Centers for Disease Control and Prevention (CDC) reports that 160,000 Americans die each year with an infectious disease as the underlying cause of death • When all infectious disease treatment costs, and lost productivity associated with illness, are taken into account it is estimated that the annual cost of infectious agents in the U.S. is greater than $120 billion each year. • Opportunities exist across multiple product categories including: disease diagnostics; vaccines; antibiotics; vector repellants and devices (including drug and vaccine delivery systems, and even simple devices such as bed nets to prevent malaria). • Prophylactic vaccines are currently valued at between $5 and 7 billion, and are expected to show a compound annual growth rate of between 9% and 11%. • The total world market for antibiotics in 2002 was estimated at over $26 billion. Total market growth rate is predicted to progress at 2.4% annually. • Diagnostics also represent a substantial potential market. • Infectious diseases remain the leading cause of death worldwide. In 1996, infectious diseases killed over 17 million people worldwide. Malaria, tuberculosis and AIDS together cause over 300 million illnesses annually.

Table B49: Diabetes Research Platform (Statewide Mid-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Endocrinology • Molecular biology • Nutrition • Epidemiology
Enabling Technology	• Bioimaging • Animal research facilities • Genomics and proteomics • Pharmaceutical sciences • Clinical pharmacology
Technology Platform	Diabetes
Applications and Products	• Drugs • Biologics • Diagnostics
Markets	• The global diabetes market was worth $18.6bn in 2005, which was an 11.5% increase from 2004 sales of $16.6bn. The U.S. has the dominant share in the global diabetes market, with 49.6% of 2005 global sales. (Source: Business Insights) • OADs represent 58% of the global diabetes market in 2005, with the remainder of sales being from insulins and analogs (40.1%) and other drugs with 1.9%. However, insulins and analogs have seen the largest sales growth at 17.3% in 2005. There has been a high level of innovation in drug delivery technology within the diabetes market during 2005–6. Key events include advances in inhaled insulins, funding into insulin pills, patch technology and pain free needles for injection. (Source: Business Insights) • Diabetes affects approximately 170 million people worldwide and is increasing, with the WHO predicting 300 million diabetics by 2025. The U.S. alone has 20.8 million people suffering with diabetes. This equates to approximately 6% of the population. It was the 6th most common cause of death as recorded on U.S. death certificates. The Global Diabetes drugs treatment market was valued of $15 billion in 2005. Oral anti-diabetics were the leading category of drugs—$8.19 billion—and showed a growth rate of 6.3% from the total global sales in 2004. The total sales for insulin products increased by 16.5% to total global sales of $6.83 billion in 2004. (Source: VisionGain)

Table B50: Bioimaging Platform (Statewide Mid-term Platform with Southern Arizona Strength) Development Pathway

Basic Research	• Physics • Engineering • Applied mathematics • Statistics • Nuclear medicine
Enabling Technology	• Optics • Multiple biomedical imaging modality platforms • Prototyping facilities • Computing and visualization resources
Technology Platform	Bioimaging
Applications and Products	• Advanced optics-based imaging • Non-optical imaging technologies • Imaging agents and image enhancement agents • Image processing and analysis tools and technologies
Markets	• The global market for medical diagnostic imaging in 2001 was estimated to exceed $14 billion, with growth expected to average 7% annually until 2007. The U.S. accounts for the largest share of revenues, followed by Europe and Asia sharing 45%, with the rest of the world totaling 12%. Slowing growth in the developed countries will be offset by increased healthcare expenditures in the developing countries. (Source: Clinica Reports) • The overall U.S. imaging equipment and auxiliary products market was estimated to be $7.9 billion in 2004 and is expected to increase at a 5.7% average annual growth rate to reach $10.4 billion by 2009. (Source: BCC Research) • The fastest growing category includes computer systems used as adjuncts for disease detection and results archiving—systems expected to command 21% of the market by 2009. (Source: BCC Research) • System whose sales are expected to grow most rapidly include direct digital radiography and computed tomography equipment, 64-slice CT scanners, 3 Tesla MRI scanners, multimodal SPECT/CT and PET/CT scanners and hand-carried ultrasound equipment. (Source: BCC Research)