Colorado's Place in the Sun: A Bioscience Future

An Action Plan to Grow Colorado's Bioscience Cluster

Colorado Office of Innovation and Technology

Support provided by:

Amgen, Inc.

Colorado Economic Development Commission

Colorado Institute of Technology

Denver Metro Chamber of Commerce

IBM Corporation, Life Sciences

State of Colorado, Governor's Office of Economic Development and International Trade

April 2003

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FINAL REPORT

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Executive Summary

As one of the most dynamic and growth-oriented sectors of the economy, the biosciences offer tremendous opportunities for economic development. The biosciences represent a major slice of our economy, reaching into a significant and vast array of industries, from drugs, medical devices and clinical care in the human and animal fields to agricultural and plant sciences. The common factor across these industries is the application of biological knowledge and processes.

Today the biosciences sector is at the forefront of creativity and innovation. Following the successful completion of the Human Genome Project, a new era of innovation is being unlocked, creating new arenas of research and application from bioinformatics to proteomics, combinatoria biology and personalized medicine. At the same time, progress in microelectronics, robotics, biomaterials, and nanotechnology is establishing new avenues for advancements in medical devices, drug delivery, and surgical practices.

In 1999, Colorado created the Governor's Office of Innovation and Technology (OIT) whose mission is to make Colorado a world leader in the formation and implementation of technology During the last four months, OIT, assisted by a management team that included industry, university and government representatives and with support provided by Battelle Memorial Institute's Technology Partnership Practice, has assessed the current status of Colorado's bioscience sector and has sought input from leaders of the state's research institutions, researchers, entrepreneurs, CEOs of biosciences companies, economic development organizations, and other services providers to determine what needs to be done to ensure that Colorado is fully realizing the opportunities provided by the revolutionary changes occurring in the biosciences. This plan outlines an action agenda designed to make the biosciences a key driver of Colorado's economy. But why should Colorado seek to develop its bioscience sector? A brief look at the history of Colorado's economy suggests that Colorado needs to diversify its technology economy just as it has had to diversity its economy in the past.

COLORADO'S ECONOMY

Colorado's economic history has been one of boom and bust. Statehood was in fact catalyzed by the economic boom generated by the discovery of gold. Although the discovery of gold was not long sustained, the mining industry continued to be the dominant sector through the end of the century. When the depression of 1893 and the repeal of the Sherman Silver Purchase Act abruptly ended the state's first boom, civic leaders recognized the need to diversify the economy, and turned to agriculture, manufacturing, tourism, and services. As a result, the economy grew steadily although more slowly through much of the first half of the twentieth century.

The next significant boom came when Colorado became home to numerous regional and national headquarters of oil and gas firms after World War II. However, during the 1980's oil bust when the price of crude oil dropped from $39 to $9 a barrel, the state sank into a severe recession. State government responded by creating the Colorado Advanced Technology Initiative (CATI),

funding the Economic Development Commission, adding a business development office, and developing several public sector infrastructure projects.

As the 1990s began, the Colorado economy began to recover and outperform the national economy. By the end of the decade, Colorado was again in a significant boom cycle. The state's population was consistently growing two and a half times faster than the national growth rate. In addition, between 1992 and 1998 Colorado had the fifth fastest growing gross state product in that nation, with an average 6.6 percent annual growth rate. Much of this new growth was spurred by information technology (hardware and software) companies. By 2000, Colorado placed first in the nation in the concentration of high technology workers.

However, the boom of the 1990s ended in bust at the turn of this century with the collapse of the dot.com phenomena and the significant downturn of the IT sector. The state has been affected by the same factors that caused the national downturn in the IT industry. However, since Colorado had a higher than average concentration in this sector, its economic impact has been more severe.

Just as civic leaders recognized at the turn of the last century that the state needed to diversify its industrial base beyond mining, so too must the leaders of this century seek to diversify in today's rapidly changing technology-based economy. While the IT industry can be expected to rebound once the national economy recovers, Colorado also needs to develop other technology sectors, most particularly biosciences, to sustain its future development, offering jobs and contributing to a healthy citizenry, too.

WHY DEVELOP THE BIOSCIENCES IN COLORADO

The bioscience sector[1] is a rapidly growing, global industry characterized by scientific and technological innovation and discovery. It involves a collection of industries with a wide variety of applications ranging from life saving drugs to cleaner bio-engineered fuels, from new medical imaging devices to healthier foods, from mapping the human genome to safeguarding against bio-terrorism. There are a number of reasons for seeking to develop Colorado's bioscience sector.

The bioscience sector offers the opportunity to create high wage, skilled jobs for Colorado residents, thereby creating wealth for Colorado citizens.

Colorado wage information indicates that jobs created in the bioscience industry are among some of the highest paying jobs within the state. Table ES-1 presents annual average employee wages received in 2000. All four subsectors of the bioscience sector exceed average annual earnings for the entire private sector. Research and testing (biotechnology) offers the highest annual wage of all the bioscience subsectors. Research and testing is also the fastest growing subsector in the state, indicating a significant opportunity for the state to foster wealth creation by encouraging the growth of this fast paced subsector. Medical devices is another high paying subsector in the state that possesses a significant presence in terms of its employment size and significance.

[1] In this report, the term "biosciences" refers to a relatively broad range of biological and life-sciences-related activity including drugs and pharmaceuticals, agricultural and organic chemicals, medical device and instrument manufacturing, and bioscience research and testing. The data on employment and establishments are taken from Dun & Bradstreet's *MarketPlace* survey.

Table ES-1: Colorado Average Annual Employee Earnings

Sector	Amount ($)
Industrial Machinery	$65,064
Research and Testing	64,331
Drugs and Pharmaceuticals	54,473
Medical Devices	47,018
Aerospace	46,505
Organic and Agricultural Chemicals	42,423
Metals	41,349
Rubber and Plastics	38,935
Entire private sector	37,553
Construction	36,967
Motor Vehicles	34,511
Hospitals and Laboratories	33,620

Note: Dollar amounts are real 2000 dollars.
Source: *Covered Employment and Wages (ES-202),* Bureau of Labor Statistics, 2000.

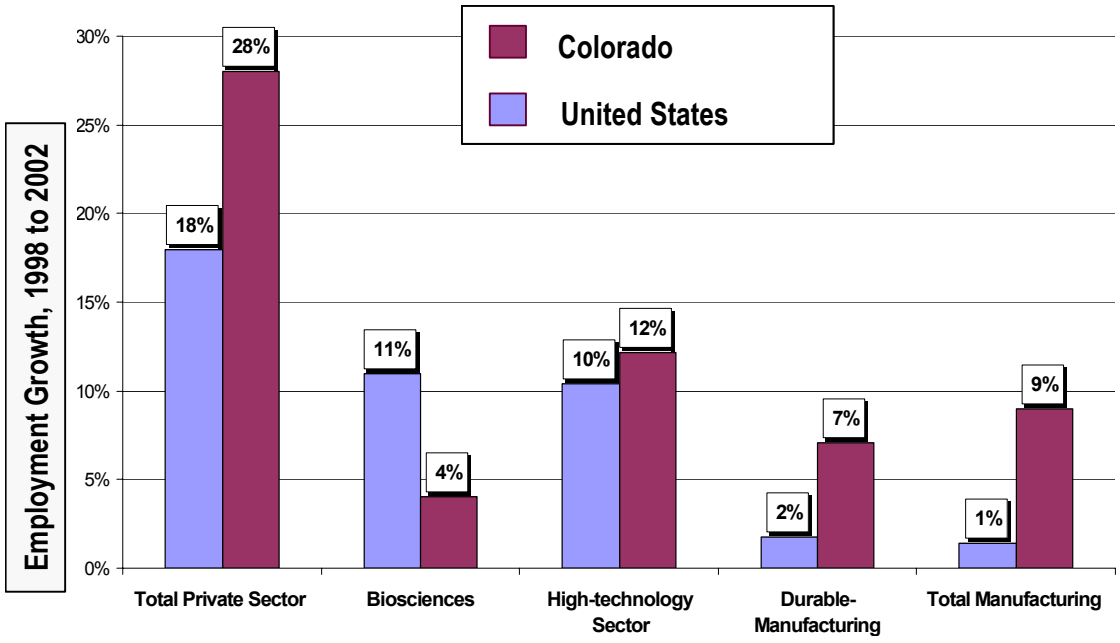
The bioscience sector offers a broad range of jobs requiring a variety of skills and education. The broad range of occupations that biosciences support is often not recognized. The biosciences offer abundant employment opportunities over the entire range of education and experience levels, from research scientists and medical doctors to technicians, laboratory researchers, and manufacturing workers. Contrary to public perceptions, the largest share of employment in the biosciences nationally consists of production and technician positions—accounting for more than 50 percent of employment in medical device industries, more than 40 percent of pharmaceutical employment, and more than 30 percent of workers within the organic and agricultural chemicals industries.[2]

The biosciences is a high growth sector. The bioscience sector of the economy is large, fast growing, diverse, and crosscutting. It involves a wide range of manufacturing, service, and research activities. Industries involved in the biosciences range from pharmaceutical development to agricultural production, from medical device assembly to biological research and testing. Moreover, the recent surge of advances in the field suggests great potential for rapid growth of new bioscience firms.

[2] Calculated from Occupational Employment Statistics, Bureau of Labor Statistics, 2000.

Nationally the bioscience industry has experienced employment growth that has surpassed increases in other sectors of the economy. Over the past four years, bioscience industries[3] have grown by 11 percent, adding 120,679 jobs nationally. During the same time period, the high-technology sector, which includes the biosciences, grew 12 percent nationally and manufacturing grew only one percent. (See Figure ES-1.)

Figure ES-1: Employment Growth 1998 – 2002



Colorado's high technology sector grew even faster than that of the nation growing by 12 percent between 1998 and 2002. While the bioscience sector in Colorado only grew by four percent in employment during this time period in comparison to a national increase in employment of 11 percent, the research and testing (biotechnology) component of the biosciences grew 95 percent in Colorado in comparison to a 35 percent growth rate nationally. Colorado has the opportunity to capture a greater share of the nation's growth in the biosciences, a sector that is expected to continue to experience significant growth.

The bioscience sector can bring stability to Colorado's economy. As an economic driver, the diversity of the bioscience sector ensures relative stability. Because demand for medical-related and food products remains fairly constant year after year, development of the biosciences provides insulation against the ups and downs of business cycles.

The biosciences is a renewable industry sector, i.e., the industry is dynamic.

Talent and companies churn and firms continue to develop products and applications for technologies on an ongoing basis. Studies of the evolution of existing bioscience centers, such as San Diego and Maryland, show that as bioscience companies succeed they tend to spawn new companies. In some cases, firms will be acquired and the original founders will move on to start other companies. In other cases, employees will leave successful companies to start ventures of

[3] Bioscience industry includes drugs and pharmaceutical, organic and agricultural chemicals, medical devices and instruments, and research and testing.

their own. In San Diego, more than 45 firms trace their lineage to a single bioscience company, Hybritech.[4] A recent study of founders of Maryland bioscience and medical instrument companies found that "the growing maturity of the bioscience/biomedical sector in Maryland has allowed it to begin to perpetuate itself through spin-offs of subsidiaries/affiliated companies, spin-outs of employees eager to run their own businesses, and 'serial entrepreneurship' by several individuals who have built and sold a series of companies."[5] Colorado not only has a base of emerging bioscience companies with the potential to generate additional firms and products as they mature but established companies such as Amgen, that are already generating additional activity in the biosciences.

The bioscience sector can contribute to the growth of Colorado's other technology sectors, such as information technology, photonics, and advanced manufacturing. The biosciences is unique in its inherent diversity, combining activity and expertise from biology, agriculture, medical sciences, animal sciences, public health, organic chemistry, engineering, and computer science, among other fields. This diversity places the bioscience sector at the center of the technology economy, serving as a focal point for the continuing convergence of technologies. The bioscience industry is increasingly interacting with other technology sectors—such as electronics, information technology, optics, and agriculture. Applications and spin-offs from the biosciences may indeed help boost other Colorado technology-based industries, such as advanced manufacturing and information technologies.

Examples of Colorado companies linking biosciences and photonics sectors:

- **Hamamatsu: develops and manufactures equipment for biomedical imaging.**
- **PhotoSense, LLC: a development stage company bringing innovative non-invasive optical sensing technology to medical, industrial and environmental applications.**
- **Hach Company: provides advanced analytical systems and technical support for water quality testing, with solutions for lab, process, and field. The company uses advance optical analytical instruments.**

Colorado has a significant foundation on which to build a bioscience cluster. Colorado has a significant bioscience research base at the state's institutions of higher education and other major non-state institutions that is growing rapidly. Colorado's total bioscience research funding reported by the NSF grew 31percent from FY 1996 to FY 2000, compared to 27 percent for the nation. In the past five years, funding for the University of Colorado Health Science Center (UCHSC) has nearly doubled from $150.5 million to $249.6 million, with an average growth of 14.2 percent per year during this five year period. For the same period, Colorado State University's (CSU) research funding in its Colleges of Veterinary Medicine, Agricultural Sciences, and Natural Sciences Resources grew from $67.8 million to $109.5 million, representing an average increase of 12.3 percent per year.

[4] Innovation Associates. *Developing High-Technology Communities: San Diego*. Washington, D.C.: Office of Advocacy, U.S. Small Business Administration, March 2000.
[5] Marsha R. B. Schachtel and Scott R. Heacock. *Founders of Maryland Bioscience and Medical Instrument Companies*. Maryland Department of Business and Economic Development and Maryland Technology Development Corporation, August 2002.

Colorado has a growing base of bioscience companies. In 2002, the state had employment of 17,681 across 604 establishments in the biosciences. Between 1995 and 2002, the number of bioscience establishments in Colorado grew slightly faster than the U.S., increasing by 35 percent compared to 29 percent at the national level. During this same time period, employment in Colorado's bioscience sector increased by four percent.

Table ES-2: Colorado Bioscience Sector

Colorado Bioscience Sector	
• **Establishments**	**604**
Percent Change '95–'02	*34.5%*
• **Employment**	**17,681**
Percent Change '95–'02	*4.3%*
• **Percent of private sector employment**	**0.76%**
U.S. percent share of private sector employment	*0.88%*

Colorado has a strong record of venture capital investment that will enable bioscience companies to expand and grow in Colorado. Lastly, Colorado has educational institutions that can produce graduates with the skills and education needed to meet the diverse needs of the bioscience industry.

Developing the bioscience R&D base of Colorado's medical research institutions will lead to high quality health care for Colorado's citizens.

Bioscience discoveries are leading to new possibilities for the diagnosis and treatment of a wide range of diseases. Breakthroughs in genomics will soon allow scientists to tailor treatments to specific diseases in specific individuals. It is estimated that within 20 years designer drugs will target specific genetic variations in diseases. Colorado has the opportunity to create an interrelated system of bioscience research, teaching and patient care that builds on its existing hospitals and research institutions to provide state-of-the art health care to its citizenry.

A Vision for Colorado's Biosciences: Colorado's Place in the Sun

Colorado's public, private and academic communities believe that by being active and strategic the biosciences can become a significant contributor to the state's future economy. Our vision for what Colorado will look like ten years from now is as follows:

> *Colorado is the preeminent life science center for the Mountain Region, serving health care needs throughout the nation and around the world by virtue of its excellent research, education, and clinical institutions. Colorado has a vibrant cluster of bioscience companies that are developing technological solutions to address health care, environmental, agricultural and veterinary, and national security needs.*

REALIZING COLORADO'S BIOSCIENCE VISION: WHAT IT WILL TAKE

The San Francisco Bay area, Boston, the Baltimore/Washington region, the New York/New Jersey metro area, and San Diego are generally regarded as the nation's premier bioscience centers. An examination of the factors that have enabled these regions to succeed in growing their bioscience base shows that they share a number of characteristics. They include

Key Success Factors

- **Engaged research organizations with active leadership**
- **Intensive networking across sectors and with industry**
- **Available capital covering all stages of the business cycle**
- **Discretionary Federal or other R&D funding support**
- **Workforce and talent pool on which to build and sustain efforts**
- **Access to specialized facilities and equipment**
- **Stable and supportive business, tax, and regulatory policies**
- **Patience and a long-term perspective**

- ***Engaged research organizations with active leadership across research, technology commercialization, and industry partnerships.*** An outstanding set of research organizations is required to become serious about the biosciences. But it takes more than simply research stature. It requires the capability to engage industry, directly or indirectly, to convert this intellectual knowledge into economic activity. Of particular importance are programs to assure development of world-class research capability; willingness to engage with industry; an institutional commitment to a role in regional economic development; and presence of a technology commercialization infrastructure.
- ***Intensive networking across sectors and with industry.*** Success in building technology clusters requires extensive collaboration among individuals and institutions spanning a range of academic disciplines and institutions, diverse industrial sectors, and the diverse and somewhat incompatible cultures of industry, academia, and state and local government. In a few leading communities like Silicon Valley, this networking has occurred naturally. However, in the vast majority of American regions, mechanisms that encourage and support networking and collaboration need to be created. The distinguishing characteristics of successful networking efforts in the biosciences are:
    - They are driven and led by industry, although government and academia may strongly participate and from time to time assume leadership roles;
    - They are either focused on bioscience exclusively or provide for a "special interest group" that can focus on this subsector of technology; and,
    - Their industry leadership is from technology generators and users, not solely from providers of business services.
- ***Available indigenous capital covering all stages of the business cycle.*** Leading bioscience regions share one characteristic: they are home to a venture capital community that is both oriented toward early-stage financing and committed to local investment. Having local venture capital funds with experience investing in bioscience companies is critical. It is also critical to have financing available for each stage of development from early-stage, proof-of-concept and prototype development to product expansion and later-stage venture financing. There must be private investment capital available to support the development of a pipeline

of bioscience start-up companies as well as established venture funding available to companies as they move into manufacturing products for the marketplace.

- ***Discretionary federal or other R&D funding support.*** To cultivate R&D excellence in particular niches that may lead to commercial relationships and start-ups, it is vitally important for regions to leverage substantial, ongoing, external, discretionary (non-formula) R&D funding. Technology leaders like Silicon Valley, Route 128 in the Boston area, and San Diego were able to leverage decades of heavy defense contracting, while Baltimore/Washington leveraged growing congressional support of federal laboratories owned by NIH, the National Institute of Standards and Technology (NIST), and the Food and Drug Administration (FDA). Securing federal centers and institutes as research anchors as well as discretionary Federal R&D funding are both important.
- ***Workforce and talent pool on which to build and sustain efforts.*** Like any knowledge-based industry, bioscience companies need a supply of qualified, trained workers. To meet the demands of newly emerging fields, new curricula and programs need to be developed by educational institutions working in close partnership with the bioscience industry. In addition to having world-class researchers, successful bioscience regions have an adequate supply of management, sales, marketing, and regulatory personnel experienced in the biosciences.
- ***Access to specialized facilities and equipment.*** Facility costs are among the most significant expenses of a new bioscience firm. These firms need access to wet lab space and specialized equipment. Since most bioscience firms initially lease space rather than purchase it, an available supply of facilities (such as privately developed multi-tenant buildings) offering space and equipment (such as incubators and accelerators) for bioscience companies is critical.
- ***Stable and supportive business, tax, and regulatory policies.*** Bioscience companies need a regulatory climate and environment that encourages and supports the growth and development of their industry. Tax policies that recognize the long development cycle required to bring new bioscience discoveries to the market can provide additional capital for emerging companies, as well as ensuring an even playing field in state and local tax policies between older, traditional industries and emerging industries such as the biosciences.
- ***Patience and a long-term perspective.*** One final lesson from every successful technology community is that success takes time. Silicon Valley and Route 128 trace their origins in electronics to the 1950s and in life sciences to the 1970s. Research Triangle Park represents a 50-year strategy that has only recently found its footing in the biosciences and is still working to develop full capability in the entrepreneurial sector. In contrast, San Diego and Maryland emerged as major bioscience centers in 12 to 14 years. While this may indicate that the time required to become a leading bioscience center can be shortened, it must be recognized that such development cannot be accomplished in a year or two or around a single project. It requires a long-term effort—in short, a marathon team effort, not a single sprint runner.

Table ES-3 provides a "gap analysis" comparing Colorado on each of these lessons with best practice bioscience states and regions on the key success factors.

Table ES-3: Comparison of Colorado to Best Practice Bioscience Regions

Factors of Success	Best Practice States/Regions	Colorado Situation
Engaged Universities with Active Leadership	✓ Universities are engaged in economic development and committed to technology transfer. ✓ Have created vehicles for technology commercialization.	✓ Higher education and bioscience industry have a weak record of collaboration. ✓ Improvements have been made in technology transfer and commercial-ization, but time is needed for technology transfer improvements to mature and greater investment in technology commercialization is needed.
Intensive Networking	✓ Active technology intermediary organizations provide a focal point for the state's biotechnology efforts. ✓ These organizations play a critical role in networking academic, industry, government, and nonprofit groups, encouraging cross-fertilization of ideas and opportunities that lead to joint endeavors.	✓ Colorado has several organizations that foster networking including the Colorado Biotechnology Assn., the Colorado Medical Device Assn., and the Colorado Alliance for Bioengineering. The Colorado Bioscience Park Aurora sponsors Bio Breakfasts and Bio West events that have been successful in showcasing Colorado bioscience companies.
Available Capital	✓ Best practice states and regions have created programs to address the commercialization, pre-seed, and seed financing gaps to help establish and build firms. ✓ Active informal angel networks investing in the biosciences. ✓ Investors include private, philanthropic, and public entities.	✓ Colorado has several local venture capital companies which invest in bioscience companies, including Sequel Ventures. ✓ A gap in pre-seed/seed funding stage exists. ✓ Limited angel networks are investing in the biosciences. ✓ Later stage funding will be necessary in future years as a critical mass of bioscience firms matures.
Discretionary R&D Funding	✓ Every major technology region in the U.S. has received significant federal discretionary funding. ✓ One or more federally designated centers exist that serve as anchors for the state or region's bioscience base.	✓ Colorado's universities have been very successful in competing for federal R&D dollars but less successful in obtaining industry R&D support. ✓ CSU is leading a regional effort to secure funding for a regional center of excellence in bioterrorism and emerging infectious diseases. ✓ Existing DOD, DOE, Commerce, HHS, and USDA federal labs and facilities exist on which to build relationships.
Talent Pool	✓ Talent increasingly provides the discriminating variable for states and regions to build comparative advantage. ✓ Educational institutions at all levels responsive to training students to meet the needs for bioscience workers at all skill levels including scientists, technicians, and production workers.	✓ Colorado has a highly educated population and available skilled workforce. ✓ Colorado attracts educated workers to relocate to the state. ✓ Colorado has not yet achieved a critical mass of companies which may discourage managers with bioscience experience to relocate to Colorado. ✓ Colorado's education and training providers produce high quality talent.

Table ES-3: Comparison of Arizona to Best Practice States and Regions on Key Success Factors (continued)

Factors of Success	Best Practice States/Regions	Colorado Situation
Specialized Facilities and Equipment	✓ Leading bioscience regions have private markets that provide facilities offering space for bioscience companies. ✓ Specialized bioscience incubators and research parks are common. ✓ Access to specialized facilities and equipment, such as core labs, and animal facilities, is readily available.	✓ Colorado Bioscience Park Aurora is the first university affiliated park focused exclusively on the biosciences in the Western U.S. ✓ Colorado has other technology parks, including CSU's Centre for Advanced Technology and Foothills Campus that can accommodate bioscience companies. ✓ Colorado has a good supply of buildings that can be adapted for use by bioscience companies. ✓ BSL-3 facility and Animal Cancer Center at CSU.
Supportive Business Climate	✓ Incentives to encourage growth of technology-driven firms through modernized economic development tool kit. ✓ Tax structures generally leveled to treat technology-driven and manufacturing firms evenly. ✓ Established brand name/image around technology themes.	✓ Colorado has a favorable business climate with stable tax and regulatory policies. ✓ Colorado has few economic development assistance programs/tools to attract, retain, and grow bioscience firms. ✓ Colorado perceives itself as lacking a national presence in the biosciences. While this may not be true, a brand/image is needed.
Patience and Long-term Perspective	✓ Building a critical mass of bioscience firms takes many years or even decades. ✓ While the early technology pioneers took 25 years to develop, more recent examples such as Maryland and San Diego took 12 to 14 years to mature.	✓ Colorado has been successful in growing the state's technology economy, particularly in IT. ✓ Colorado does not have a history of long-term, sustained and continuous state investment in technology development.

To build Colorado's bioscience future will require an alliance of business, higher education and government with each playing appropriate synergistic roles. It will require:

- **Connections.** Colorado's academic, bioscience industry, and public sectors do not have a strong history of collaboration. In part due to the nature of the state's historic strengths in the medical devices industry, which at the time did not partner extensively with research organizations, industry and higher education have not "connected." Another contributing factor is the relative success of Colorado's higher education institutions in successfully securing federal funds. Relationships are not strong and neither industry nor academe is networked formally or informally. This plan identifies concrete ways to build these relationships.
- **Collaboration across organizations and sectors, and between companies.** Building sustained relationships and collaboration occur in many ways, whether it be sponsored research, education and training, or simply technical assistance and problem solving support. Like two ships in the night passing unseen, business and higher education in Colorado fail to take maximum advantage of each other's assets, needs, and opportunities that can help build both research excellence and establish more competitive industries. Many of the specific actions in this plan will require increased collaboration for their success.
- **Champions from both the public and private sectors who will commit to working to build the biosciences over the long-term.** CEO-level bioscience executives have not emerged historically to lead efforts to build Colorado's bioscience industry. Public, academic, and industry leaders have been focused on addressing technology infrastructure without direct attention to how this infrastructure may interact with the other sectors. This is not necessarily bad, but the sum would be greater than the parts if the three sectors would interact and develop a more cohesive approach. Also, Colorado's early success in communications and computing resulted in less attention to bioscience opportunities by the public sector. This overall plan, driven by industry-led groups and organizations, will require champions in the private, public, and academic sectors.
- **Commitment and continuous dedication to quality and long-term investment of resources.** Building technology-driven economies around biosciences takes long term commitment. Success needs to be measured over many years as the bioscience business model is not one (due to regulatory approvals and clinical trials) that results in quick introduction of new products although the time period varies across testing and diagnostics to drugs and treatment interventions. Colorado must not only embrace biosciences for today but for many tomorrows as well. This plan lays out a program for private and public action that will be accomplished over the coming five years. The results of these actions will be seen over the next decade and more.

OPPORTUNITIES FOR COLORADO

Where Colorado Stands Today

Colorado has a strong medical device industry employing more than 11,000 people and accounting for 68 percent of total bioscience employment in the state. The medical device sector is the only bioscience subsector in which Colorado has a specialization greater than the nation. This sector is 52 percent more concentrated in Colorado than nationally. However, Colorado's medical device sector experienced a five percent decline in employment between 1998 and 2002 at the same time that this industry grew two percent nationally.

Colorado's research and testing (biotechnology) industry has experienced astonishing growth, nearly doubling in employment from 1998 until 2002. In addition to outpacing all other Colorado bioscience subsectors, growth in research and testing, which experienced a 95 percent growth in employment between 1998 and 2002, is well above the national growth rate of 34 percent during the same time period. The large employment increase in the state's research and testing subsector has helped this segment to significantly increase its share of total bioscience employment. The effect of such rapid growth has led to an increasing level of employment concentration in the research and testing subsector. In 1998, Colorado research and testing held a location quotient of 0.66[6]. The subsector's current location quotient is 88 percent of the national average. *This increasing location quotient is highly significant when considered in the context of a state that has experienced employment growth across the entire economy at a rate above the national average.*

Key Facts: Colorado Bioscience Subsectors

- Medical devices, the largest subsector, employs 11,973 and accounts for 68% of Colorado bioscience employment.
- Medical devices is the most specialized subsector with a highly significant LQ of 1.52.
- Employment in research and testing (biotechnology), the fastest growing subsector in Colorado, increased by 95% between 1998 and 2002.
- Research and testing is becoming a specialization, now accounting for 13% of the bioscience sector compared to 7% four years ago.
- Drugs and pharmaceuticals, the second largest subsector, employs 2,782 and grew by 3% in employment.
- Organic and agricultural chemicals, the smallest and least regionally specialized subsector, employs only 576.

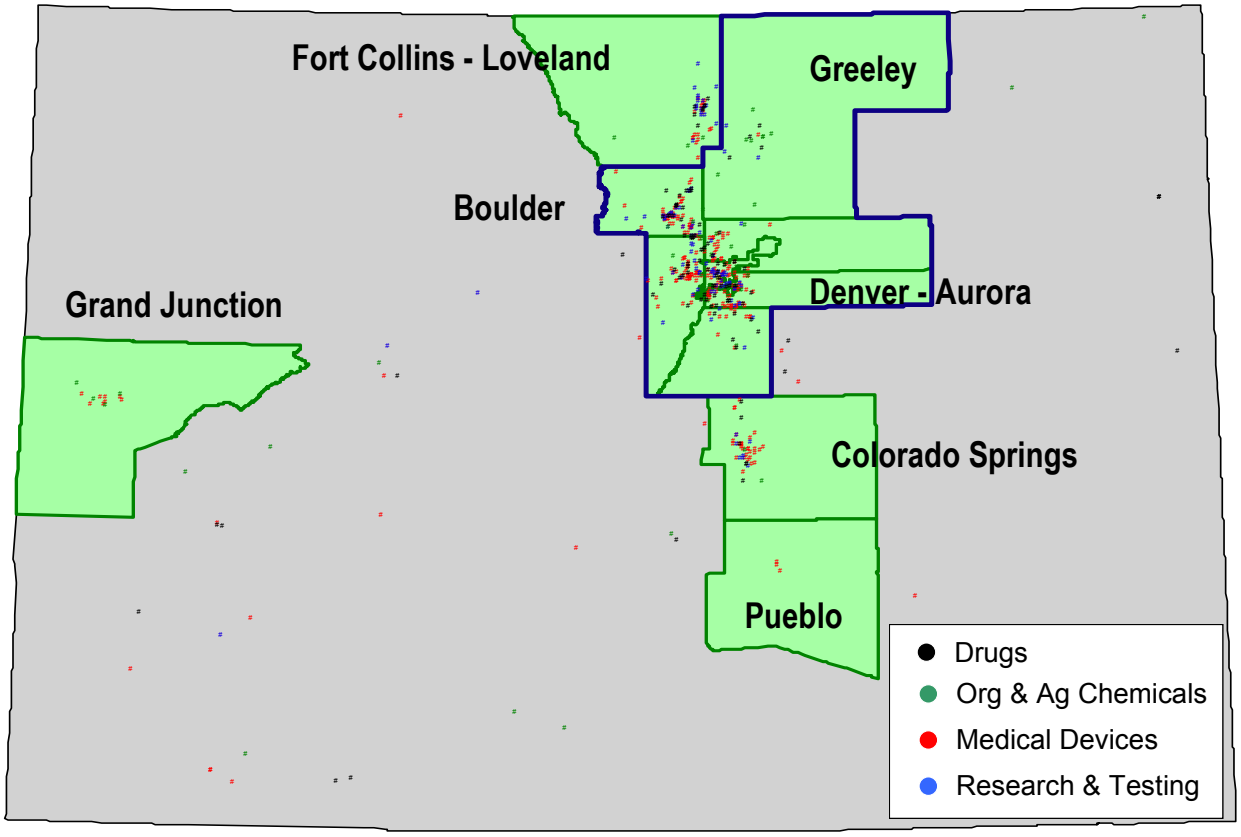
Colorado has a diverse bioscience research base. An examination of the fields of research within the biosciences in which Colorado research institutions have strengths reveals that there is significant institutional depth, particularly within the University of Colorado, Colorado State University and National Jewish Medical and Research Center, in a broad range of bioscience, biomedical and related disciplines. While Colorado has clear strengths in clinical human medicine, there also exists a substantial base of expertise in basic biological sciences, animal sciences, and plant and agricultural biosciences.

Colorado's bioscience industry cluster is geographically concentrated. Colorado's bioscience industry is predominantly clustered within the Greater Denver region. (See Figure ES-2.) Three of the Colorado

[6] Location quotients are a common measure of the concentration of a particular industry or industry sector in a region relative to a reference area. A location quotient greater than 1.0 indicates that the region is relatively concentrated in the particular industry. In this report, location quotients are used to report state industry concentrations relative to the United States.

metro areas that make up the Denver (includes Aurora)-Boulder-Greeley (includes Fort Collins-Loveland) Consolidated Metropolitan Statistical Area (CMSA) account for 80 percent of the state's bioscience employment and 73 percent of establishments. This clustering of companies offers an opportunity for Colorado to create a critical mass of bioscience companies by networking existing firms and providing an infrastructure to support their growth and development. Biosciences firms tend to geographically concentrate around academic health centers and research universities and Colorado's concentration provides a basis for further building a critical mass of firms.

Figure ES-2: Geographic Distribution of Colorado's Bioscience Establishments



Colorado's Competitive Advantages

Colorado is not alone in seeking to grow its bioscience industry cluster. State and regions across the country are focusing resources on creating an environment that will encourage and facilitate the growth of their bioscience sectors. Colorado should build on its comparative advantages as the state seeks to grow the biosciences. These include:

A highly educated population and available skilled workforce. Colorado has one of the most highly educated populations among the 50 states. In 2000, 11.25 percent of Colorado's population aged 25 and older held graduate or professional degrees as compared to nine percent nationally. Colorado ranks first among the fifty states in the percentage of the population aged 25 and older that hold a Bachelor's degree or higher (34.6 percent). Colorado also has a base of science and engineering workers ranking second in the nation in the percentage of scientists and engineers in the workforce (1999).

Dynamic entrepreneurial economy. Coloradoans support risk taking and embrace new opportunities. Evidence of Colorado's strong entrepreneurial culture is found in the fact that Colorado ranks extremely high in metrics that attempt to rank its level of entrepreneurial development. In the Progressive Policy Institute's *The 2002 State New Economy Index*, Colorado ranked fourth in the nation in economic dynamism, which is defined as a state's ability to foster the creation of new firms, support firms that innovate, and cultivate a culture that is epitomized by fast-growing, entrepreneurial companies. This dynamism ranking was comprised of several metrics.

- The number of jobs in gazelle companies (companies with annual sales revenue that have grown 20 percent or more for four straight years) as a share of total employment. In the gazelle category, Colorado ranked thirteenth in the nation in 2002.
- "Job churning," which is defined as the number of new start-ups and business failures combined as a share of all establishments. Steady growth in employment masks the constant churning of job creation and destruction, as less innovative and efficient companies downsize or go out of business and more innovative and efficient companies grow and take their place. While such turbulence increases the economic risk faced by workers, companies, and even regions, it is also a major driver of economic innovation and growth. Colorado ranked sixth in 2002.
- The number of initial public offerings (IPOs), a weighted measure of the value and number of initial public stock offerings of companies as a share of gross state product. In this category, Colorado ranked fourth in the nation in 2002.

In a study prepared by the Milken Institute for the California Technology, Trade and Commerce Agency's Division of Science, Technology and Innovation, Colorado ranked second after Massachusetts as the best positioned state to succeed in the technology-led information age.

Attractive Life Style and Environment. Colorado offers recreational opportunities and other amenities that offer a quality of life that many people, particularly highly educated, skilled technical workers, find attractive. While quality of life is a subjective factor, it is clear that Colorado's geography, climate, recreational and cultural amenities serve to draw people to the state. Between 1995 and 2000, the state's population grew by thirteen percent, much faster that the national rate of six percent. Colorado ranks third in net migration after Nevada and Arizona.

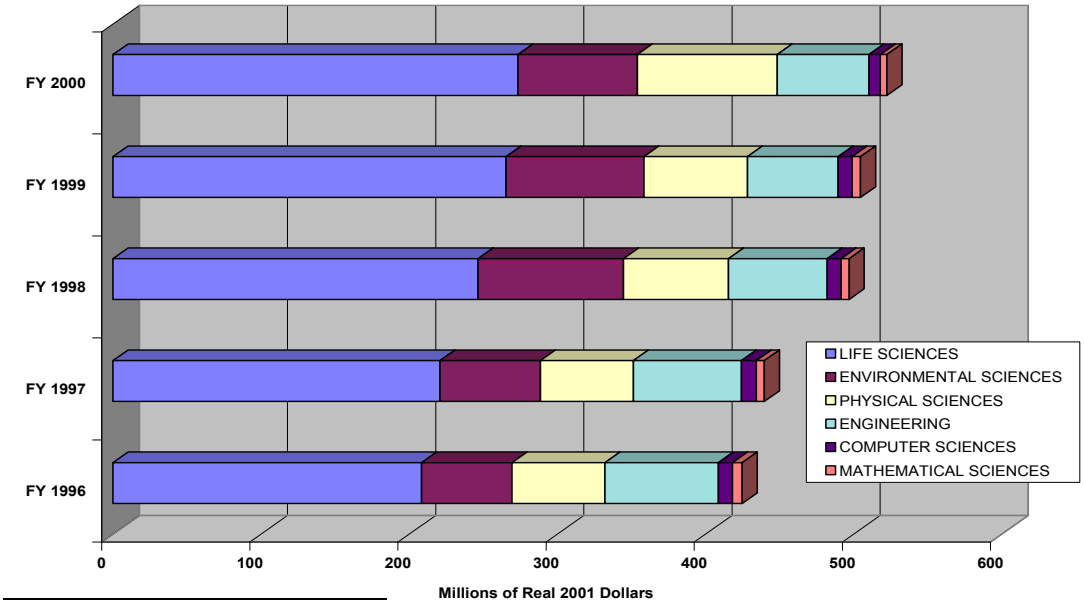
Surveys conducted on behalf of the Colorado Office of Economic Development found that Denver is highly rated among young professionals as a place to work and as a relocation site.

Anecdotal evidence indicates that graduates of Colorado's institutions of higher education tend to want to remain in the state, in some cases taking positions for which they are overqualified in order to remain. A study conducted for the National Science Foundation, which examined interstate migration of recent science and engineering graduates, found that 57 to 66 percent of students that had received degrees in Colorado were working in the state after graduation. In addition, Colorado ranked in the top quartile of states in the degree to which the state is a net importer of science and engineering graduates.[7]

Attractive business climate. Overall, the business climate in Colorado is favorable with a stable tax and regulatory environment. Colorado has achieved an A rating on key measures of business climate during the last seven years, the only state in the country to achieve this ranking, as measured by the Corporation for Enterprise Development that ranks states in term of economic performance, business vitality and development capacity.[8]

Research institutions with strengths in selected bioscience areas. Colorado is a major source of university based scientific research—bringing substantial funding into the state—and outpacing the state's overall ranking in population. Based on research funding data compiled by the NSF, Colorado's university research base in science fields totaled $559.7 million in FY 2000. This level of funding ranked Colorado 18th among the 50 states and the District of Columbia compared to its population rank of 24th in the nation. Bioscience research, which accounts for a substantial $273 million in total university research in Colorado, grew 31 percent from FY1996 to FY2000, compared to 27 percent for the nation.

Figure ES-3: Academic R&D Spending in 11 Colorado Institutions, FY 1996–2000



[7] Louis Tornatzky, Ph.D., Denis Gray, Ph.D.,/Stephanie Tarant, and Julie Howe. *Where Have All the Student Gone: Interstate Migration of Recent Science and Engineering Graduates*. Southern Technology Council, February 1998.

[8] Corporation for Enterprise Development. *Development Report Card of the States 2002*. Washington D.C., December 2002.

Colorado's university-based bioscience research is predominantly centered on the University of Colorado and Colorado State University,[9] both designated by the Carnegie Foundation as being in the highest level research classification group of "Doctoral/Research Universities – Extensive." Within these institutions, there are a number of individual departments that stand out within the NIH rankings data, including:

Institution	Department	NIH Rank
		Among medical schools
UC Health Sciences Center	Pediatrics	3rd
	Biology	7th
	Pharmacology	7th
	Pharmacy	11th
	Psychiatry	12th
	Medicine	14th
		Among universities
University of Colorado at Boulder	Psychology	10th
	Chemistry	13th
	Genetics	18th
Colorado State University	Veterinary Medicine	3rd

Source: NIH 2001 Extramural Awards to Medical School Departments, NIH 2001 Extramural Awards.

Colorado is also home to National Jewish Medical and Research Center, a private non-profit biomedical research institution. National Jewish ranked thirteenth among independent hospitals for NIH-funded biomedical research with a total of $26.7 million in NIH funding.

There are at least four federal laboratories with operations in Colorado: the National Oceanographic and Atmospheric Administration (NOAA) Environmental Technology Laboratory and the National Institute of Standards and Technology laboratory both located in Boulder, the National Renewable Energy Laboratory in Golden, and the Centers for Disease Control and Prevention (CDC) lab in Fort Collins. Other Colorado institutions that contribute to the state's bioscience base include Children's Hospital-Denver, the VA Medical Center-Denver, USDA and other related laboratories at the NRRC in Fort Collins.

Strong Bioscience Infrastructure. Colorado has developed research parks and facilities that can support bioscience companies at each stage of the business life cycle, from early stage start-up to established companies with manufacturing operations. The **Colorado Bioscience Park Aurora** is a 160 acre research park located adjacent to the new UCHSC/UCH campus at Fitzsimons. Formally affiliated with CU, the Bioscience Park is the first of its kind west of the Mississippi. The first research park building, the Bioscience Park Center, opened in October 2000. The Bioscience Park Center houses the Park's administrative offices and provides incubator space to start-up bioscience companies as well as built to suit space for expansion stage companies. The

[9] Other institutions of higher learning, such as the Colorado School of Mines, are also engaged in bioscience research, but at significantly lower levels of research volume versus the University of Colorado and Colorado State University.

building currently houses 18 start-up bioscience companies and three academic groups. Companies locating in the Park will have access to scientific support services and facilities and the opportunity to enter into collaborative relationships with faculty and researchers at the UCHSC/UCH campus.

The Colorado State University Research Foundation, in conjunction with Everitt Enterprise of Fort Collins, has developed a multi-use technology park, known as the **Centre for Advanced Technology,** located directly south of the main campus of Colorado State University. The park currently houses and is expected to attract additional companies that wish to have a collaborative relationship with CSU. The Centre is home to the Natural Resources Research Center (NRRC) which is a campus of five buildings that house between 800 and 1000 federal employees. Companies housed at the Center include Atrix Laboratories, Inc. and Summit Plant Laboratories. **The University of Colorado Research Park** is located in Boulder and seeks to attract tenants desiring a collaborative relationship with the university. The **CSU Foothills Campus** is currently in the early stages of development and also offers a new venue for bioscience industry.

Colorado has several incubators that provide support for start-up technology companies including bioscience companies, such as CTEK, CVC (Colorado Ventures Center), Colorado Springs Technology Incubator, and the Ft. Collins Virtual Incubator. Each of these incubators provides support to technology entrepreneurs and start-up companies. CTEK has some space available to house companies but their main focus is providing mentoring and advice to client companies. Colorado also has an inventory of existing buildings that can readily be converted for use by bioscience companies.

Quality manufacturing companies that have mass customization capabilities. One of the advantages Colorado has over even established bioscience areas is the ability to support the cluster at all stages of development from research and development through manufacturing and sales. Leading bioscience centers such as Boston and San Francisco are often not cost competitive for manufacturing. In Massachusetts, for example, only about 10 percent of the state's biotechnology companies are currently involved in manufacturing and of those, more than half do their manufacturing out of state.[10]

Colorado has a strong technology-based manufacturing sector. Colorado has more than 6,000 manufacturing companies with more than 205,000 Colorado employees. These firms produce a diverse mix of manufacturing products including high technology instruments, machinery, computer equipment, aerospace equipment, medical devices and pharmaceuticals. Colorado's strength in manufacturing means that the state will be able to capture the downstream, value added jobs that will be created by bioscience companies over the long run.

Comparative Disadvantages

While Colorado is in a strong position to compete with other regions in developing its bioscience base, there are several areas in which Colorado is not as competitive as other regions with established or emerging biosciences bases. These include:

- ***Colorado's bioscience industry base is at an early stage of development***. Colorado has a rapidly growing research and testing (biotechnology) sector, with many small companies that have yet to introduce products in the market. Likewise drug and pharmaceutical

[10] The Boston Consulting Group and the Massachusetts Biotechnology Council, *MassBiotech 2010*, 2002.

establishments in Colorado employ an average of only 24 workers whereas nationally the average drug and pharmaceutical establishment employs 72 workers. These factors suggest that Colorado's bioscience sector has not yet reached the maturity of other leading bioscience centers. There is reason to believe however, that Colorado's drugs and pharmaceuticals sector will grow as more of Colorado's biotechnology research and testing firms mature.

- ***Higher education and bioscience industry have a weak record of connectivity and collaboration.*** In 2000, of a total R&D budget of $353.5 million at the University of Colorado system, only 2.6 percent came from industry. At Colorado State University, 4.3 percent of its 2000 R&D funding came from industry. Nationally, 7.2 percent of total university R&D funding at universities came from industry in 2000.[11] The lower percentage of funds coming from industry going to CU and CSU is due in part to the universities very successful track record in attracting federal R&D dollars. The one Colorado university with a significant percentage of its R&D funding coming from industry, albeit with a much smaller research budget of $21.8 million, is the Colorado School of Mines with 36.1 percent of its R&D funding coming from industry.
- ***Industries and universities in Colorado are not capturing the full potential commercialization of research findings***. Major improvements and changes are underway by the University of Colorado System and efforts continue at CSU and CSM to improve the management and transfer of intellectual property. Meanwhile, additional ways to move research toward commercialization, reduce to practice research findings, access capital, and provide mentoring by serial bioscience entrepreneurial managers will be needed to move university research findings into commercial products. The birth of new bioscience enterprises has remained strong in Colorado at the same time there has been an ongoing death of firms. As a result, Colorado has failed to build a critical mass as quickly as might be expected given its entrepreneurial culture and the size of its private venture capital base.
- ***Lack of strong public sector initiatives in support of the bioscience industry.*** While Colorado has undertaken a number of initiatives in the communications and information technology sectors in recent years, there has been less focus on biosciences with the notable exception of the new development at Fitzsimons and the Centre for Advanced Technology and regional biocontainment lab facility at CSU.
- ***Lack of perceived national presence***. Representatives of Colorado's bioscience sector indicated in interviews that a disadvantage of Colorado as a location for bioscience companies is the fact that the state does not have a national image as a center of the biosciences. Yet many reports in the media often cite Colorado as an emerging bioscience region. There appears to be a need to brand Colorado in the biosciences and to increase efforts to market Colorado's bioscience assets.

[11] Source: National Science Foundation/Division of Research Science Statistics, Survey of Research and Development Expenditures at Universities and Colleges.

COLORADO'S BIOSCIENCES FUTURE: LEVERAGING COLORADO'S UNIQUE ASSETS

Colorado should build its bioscience base by focusing on its unique assets and capabilities. These include first and foremost its entrepreneurial culture and its strong base of research institutions. It is recommended that Colorado grow the biosciences by:

- Nurturing home grown businesses;
- Creating excellence in selected bioscience research areas; and,
- Addressing the complexity of the research and industry enterprise through cooperative endeavors.

Build Our Own

Colorado has a history of strong entrepreneurial development, ranking second among the fifty states in terms of new business start-ups in 2000. Colorado's bioscience sector consists primarily of small companies that have been started in Colorado. In 2000, Colorado's research and testing (biotechnology) companies had an average of 17 employees while the state's drugs and pharmaceutical companies had an average of 24 employees. Colorado has a rapidly growing base of research and testing (biotechnology) companies that, as they mature, will lead to growth in the state's drug and pharmaceuticals sector.

Colorado can foster the creation and growth of new start-up companies by providing support for entrepreneurs and emerging bioscience companies, ensuring the availability of venture capital in all stages of a company's life cycle and improving the commercialization of university inventions.

Create Research Excellence in Selected Bioscience Areas

Colorado's bioscience research base is very diverse. An examination of publications data shows that UCHSC and CU-Denver published more than 100 papers in each of 25 different bioscience fields between 1997 and 2001. Similarly, the University of Colorado in Boulder and Colorado Springs published more than 100 papers in 19 different bioscience fields during the same time period. Colorado State University published more than 100 papers in six additional fields of the biosciences. Over the last three years, investigators at National Jewish and Medical Research Center have published hundreds of scientific articles in the areas of immunology, respiratory medicine and allergy. A tighter focus on selected niches will be needed if Colorado is to develop concentrated strengths to catch up with leading bioscience regions.

Based on a consideration of not only Colorado's research strengths but also where that research intersects with the state's industry base, competitive advantages and market opportunities, the following areas are identified as having near-term potential for development in Colorado:

Pharmaceutical Biotechnology – This focus area would build on Colorado's considerable resources in basic biological sciences and expertise in specific fields of medicine and take advantage of the University of Colorado's Center for Pharmaceutical Biotechnology and Colorado State University's Bioprocessing Center. It would also support Colorado's existing base of companies involved with drug development and drug delivery systems.

Medical Devices and Bioengineering – Colorado is already home to a concentration of medical device companies and the state's research institutions conduct significant research in bioengineering. The CU College of Engineering estimates that the College conducts $6 million in bioengineering research annually. CSU and CSM also have research strengths in particular areas of bioengineering. This focus area would build on Colorado's competencies in biomaterials, BioMEMS/nano-technology.

Plant and Agricultural Biotechnology – Colorado is well positioned to assume leadership within the fast moving field of plant biotechnology. Existing Colorado plant bioscience assets include the National Seed Storage Laboratory at CSU, CSU's Departments of Bioagricultural Sciences and Pest Management, Soil and Crop Sciences, Biology, and program in Horticultural Biotechnology, and the University of Colorado's strengths in plant physiology.

Biosecurity – The field of biosecurity is likely to experience tremendous growth as the United States and the world responds to a wide array of bioweapon threats. CSU and the CDC's labs in Fort Collins are leading a proposal that includes a number of regional research institutions for a regional center of excellence in bioterrorism and emerging infectious disease. Whether or not this center is funded, Colorado has existing assets, including the CDC lab in Fort Collins, which could contribute to developing a counter-terrorism research and commercial sector.

Over the longer term, additional focus areas that appear to have market potential in the mid-to-long term would be identified. These may include metabolics, which examines the chemical changes in an organism generating energy or materials required for life processes, computational biology/bioinformatics, and biomedical lasers and optics. Table ES-4 shows how the current and emerging strengths of Colorado's research institutions relate to the proposed technology platforms.

Special attention should be paid to promoting the convergence of health care and biosciences with other areas including information technology, optics, robotics, and microelectronics to create personalized or "genomic" medicine.

Table ES-4: Technology Platform Linkages Across Core Competencies: Current and Emerging

Technology Platform	Basic Research	Enabling Technology	Applications
Areas Judged by Battelle to Have Near-Term Growth Potential (Next Five Years)			
Pharmaceutical Biotechnology	Biological and Medical Sciences	Clinical Research Pharmaceutical Sciences and Pharmacology MCD Biology Microbial Pathogenesis RNA Biochemistry Structural Biology Genomics Proteomics Computational Biology Bioprocessing	• Drugs/Therapeutics for Mycobacterial Diseases • Neurological Drugs • Cancer Drugs • Diabetes Drugs • AIDS Drugs • Psychiatric Drugs

Technology Platform	Basic Research	Enabling Technology	Applications
Areas Judged by Battelle to Have Near-Term Growth Potential (Next Five Years)			
Medical Devices and Bioengineering	Engineering	Chemical Engineering Polymer Science Biomaterials MEMS/Nanotechnology Electrical Engineering Mechanical Engineering	• Implantable materials • Bioscaffolds • Tissue Engineering • Orthopedics • Drug Delivery • Intelligent Devices • Diagnostic Instruments • Biosensors
Plant Biotechnology	Plant and Agricultural Sciences	Plant Genomics Crop Breeding Transgenic Plants Germplasm Preservation Plant Pathogens Bioprocessing Biotech Risk Assessment Environmental Sciences	• Transgenic Plants with pest/pathogen resistance • Pharmaceuticals via Plant Pathways • Bioprocessing of "Farmaceuticals" • Environmental Monitoring
Biosecurity	Microbiology	Immunology and Infectious Diseases High Level Biocontainment Pharmaceutical Sciences and Pharmacology MCD Biology Microbial Pathogenesis Microbiology and Vector-Borne Diseases Bioprocessing Environmental Sciences	• Vaccines • Diagnostics • Drugs and Therapeutics • Environmental Monitoring
Metabolics	Metabolics	Clinical Research Metabolics Immunology Endocrinology Nutrition Cell Biology Cancer Biology/Carcinogenesis	• Cancer Drugs • Anti-Inflammatory Therapeutics • Pro-Inflammatory Therapeutics • Analytical Instruments
Computational Biology & Bioinformatics	Mathematics and Computer Science	Mathematics Computer Science Statistics Genomics Proteomics Biological Sciences	• Basic Science Discoveries • Drug Discovery and Development
Biomedical Lasers and Optics	Physics	Mechanical and Electrical Engineering Laser Physics Optical Physics MCD Biology Biochemistry and Chemical Engineering	• Analytical Instruments • Measuring Devices • Surgery and Invasive Diagnostics • Advanced Biomedical Imaging

Address the Complexity of the Bioscience Research and Industry Enterprise Through Cooperative Endeavors.

The bioscience sector stands out from other technology sectors in the close relationship that exists between the research and industry enterprise. Major new products and innovations in the biosciences are frequently related to basic research discoveries while in other technology sectors the links are less direct. On average, biotechnology companies spend over 50 percent of their revenues on R&D, while pharmaceutical companies spend more than 20 percent. Across all industries, Standard and Poor's Compustat database estimates that industry R&D represents approximately four percent of sales. As a result, bioscience companies seek close interactions with academic researchers. Major university and non-profit research institutions are not only the key to basic research discoveries that can generate product leads for bioscience companies, but more importantly create an environment in which bioscience companies can flourish.

Colorado has both a base of bioscience companies and leading research institutions yet these research institutions are not closely tied to industry. In order to grow Colorado's bioscience sector, closer collaboration between industry and academic researchers will be required. To achieve such collaboration will require that industry develop a greater understanding of the mission of the research institutions and the incentives that drives behavior of researchers and faculty, and that the research institutions provide access and respond to industry and entrepreneurs.

Multi-disciplinary and cross-institutional linkages will also be required to develop the type of research excellence described above. For example, The University of Colorado Center for Pharmaceutical Biotechnology is linking CU Health Sciences Center Pharmacology with the Boulder-based disciplines of Pharmaceutical Sciences and Chemical and Biological Engineering. The Center is serving a coordinating role in a range of research areas and serves as a conduit for a significant number of pharmaceutical and biotechnology company-funded projects. If Colorado is to develop a cluster in the pharmaceutical biotechnology area, the center will need to extend its interaction with Colorado State University and other state bioscience research establishments. Another example is the proposed Rocky Mountain Institute for Biosecurity Research at CSU that is integrating statewide and regional expertise in infectious diseases, plant and animal biological agents and atmospheric sciences under one umbrella organization to coordinate and plan projects to meet pressing needs.

Similarly research and education initiatives that provide essential multi-disciplinary programs that will bring critical support to the bioscience industry need to be supported through their early phases. A good example is the computational biology program, which is a collaborative effort among CU campuses and located at the Denver campus.

The Colorado Tobacco Research Program (CTRP) has been another successful multi-disciplinary and cross-institutional program. The CTRP supports comprehensive clinical, basic science, mental health, and evaluative research that serve Colorado's tobacco and substance abuse related health care needs. This approach serves as a good example of how to build relationships across disciplines and institutions to address complex issues and also bridge state policy priorities to the bioscience research and industry communities.

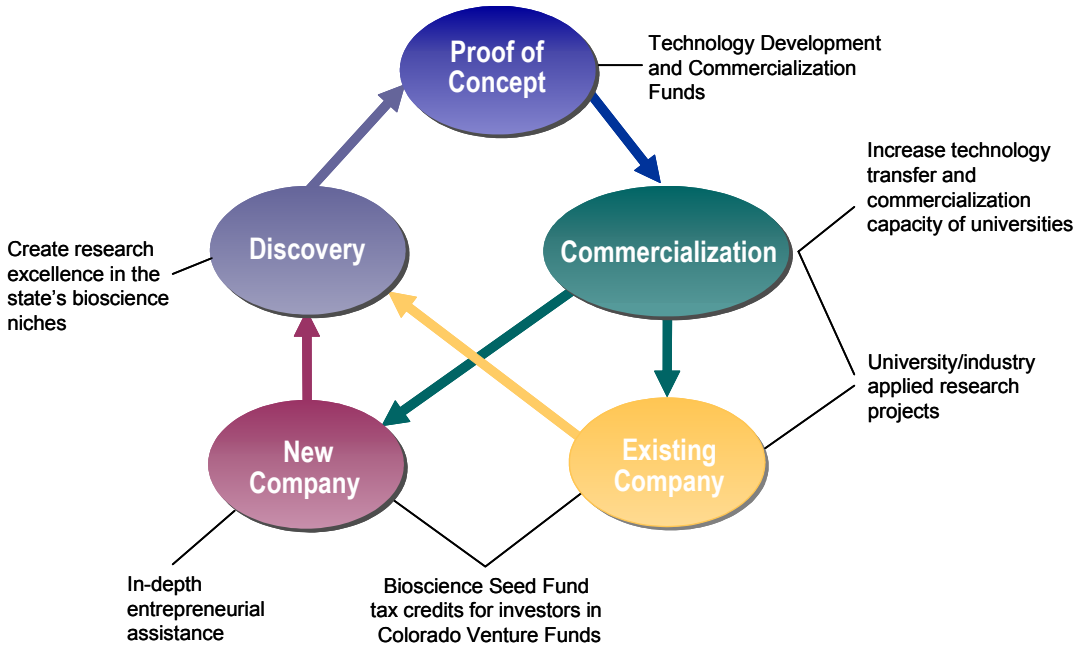
Lastly, the interrelationship of state policy and the biosciences will need to be recognized. The bioscience industry is a regulated industry and as such is impacted by federal and state health and

regulatory policies. It will be important that state and local governments work cooperatively with the bioscience industry to ensure that policies are not enacted that would discourage the development of the biosciences in Colorado.

THEMES AND ACTIONS: AN ACTION AGENDA TO POSITION COLORADO IN THE BIOSCIENCES

To move Colorado from having an emerging biosciences sector to the biosciences being a foundation of Colorado's economy, will require an innovation climate in which research is advanced toward commercialization, there are proactive technology transfer interfaces, and new companies are created and emerging companies succeed and grow. Figure ES-4 presents the components of Colorado's bioscience plan that address each stage of the innovation cycle.

Figure ES-4: Overview of Colorado's Bioscience Plan.



Three strategies are proposed to grow Colorado's bioscience cluster.

- **Strategy One**: Create a business climate sensitive to and supportive of the needs and issues facing bioscience firms.
- **Strategy Two**: Grow the state's bioscience cluster by creating a bioscience entrepreneurial culture that turns research discoveries into new products and services and cutting edge firms and provides appropriate incentives to research institutions and industry.
- **Strategy Three**: Expand the research base and build research excellence in the state's bioscience niches.

Table ES-5 lists the proposed strategies and actions which are described below.

Table ES-5: Summary of Proposed Strategies and Actions

Strategy	Action
STRATEGY ONE: Create a business climate sensitive to and supportive of the needs and issues facing bioscience firms.	Enact a package of tax incentives to be triggered as the state's economy improves, to support the growth of Colorado's bioscience companies.
	Appoint a high-level Bioscience Advocate within state government.
	Review and ensure that state Medicaid policies relating to pharmaceuticals do not discourage building the bioscience industry in Colorado.
	Strengthen the voice of the bioscience industry in Colorado by forming a unified Bioscience Industry Association.
	Create a focus on the biosciences within the Governor's Office of Economic Development and International Trade.
	Develop and implement an industry-led, comprehensive communications strategy to educate and inform citizenry, elected officials, the nation and world about Colorado biosciences.
	Use the Colorado Institute of Technology to work with industry to identify and address emerging bioscience workforce needs at all levels.
STRATEGY TWO Grow the state's bioscience cluster by creating a bioscience entrepreneurial culture that turns research discoveries into new products and services and cutting edge firms and provides appropriate incentives to research institutions and industry.	Provide comprehensive in-depth entrepreneurial assistance to bioscience entrepreneurs and companies.
	Create a privately managed Colorado Bioscience Seed Fund and encourage a bioscience focus for angel investor networks.
	Enact legislation that would use state tax credits to guarantee investments in a "fund of funds" that would invest in private venture capital companies willing to invest in Colorado companies.
	Undertake activities that celebrate successful bioscience role models.
	Explore opportunities to establish plant-and animal-based pharmaceutical and nutraceuticals production within Colorado.
	Continue to build and strengthen technology transfer/commercialization capacity of universities.
	Create Technology Development Funds to support proof of concept and other commercialization activities.
STRATEGY THREE Expand the research base and build research excellence in the state's bioscience niches.	Complete full physical development of UCHSC/UCH Fitzsimons Campus to help anchor Colorado's bioscience research base for the future.
	Encourage collaborative partnerships between academic researchers and industry by providing funding for collaborative university/industry applied research projects, streamlining industry contracting, and designating an industry liaison.
	Identify opportunities and compete for national and federal institutes and centers of excellence in Colorado's bioscience niche areas.
	Develop a pilot program of product development and technical assistance support for the medical device, advanced manufacturing and bioagriculture development industries.

Strategy One: Create a business climate sensitive to and supportive of the needs and issues facing bioscience firms.

Action One: Enact a package of tax incentives, to be triggered as the state's economy improves, to support the growth of Colorado's bioscience companies. Traditional tax incentives put in place to encourage the establishment and growth of companies—tax credits for job creation and investment—generally do not benefit young bioscience companies. In 1999, Colorado enacted legislation that allows qualified taxpayers to obtain a refund for Colorado sales and use taxes paid on purchases of personal property used directly and predominantly in R&D of biotechnology. It is recommended that Colorado develop a legislative package of additional tax incentives to encourage the growth of emerging bioscience companies that would be triggered as the state's economy improves. Consideration should be given to:

- Allowing biotechnology companies to sell unused Net Operating Loss (NOL) carryover to another tax payer.
- Allowing bioscience companies with unused amounts of research and development tax credits that cannot be applied in the credit's tax year to transfer those credits for use by other corporation business taxpayers in the state. Consideration could also be made to making R&D tax credits refundable.

Action Two: Appoint a high-level Bioscience Advocate within state government. Colorado is fortunate in that it has multiple organizations that are seeking to promote the development of the state's bioscience cluster. There is, however, no single point of contact that speaks for, or represents, the entire spectrum of bioscience interests. Nor is there a point of contact in state government for the bioscience industry. It is recommended that Governor Owens appoint a Bioscience Advocate, similar to the Aerospace Advocate, to be housed within the Governor's Office of Innovation and Technology. The appointment of a Bioscience Advocate will demonstrate the state's commitment to developing and supporting Colorado's bioscience sector. The Advocate will work closely with the bioscience sector, including both industry and academia, to identify needs and develop proposals to address those needs. The Bioscience Advocate will be responsible for coordinating implementation of the Colorado Bioscience Plan and tracking progress.

Action Three: Review and ensure that state Medicaid policies relating to pharmaceuticals do not discourage building the bioscience industry in Colorado. While many states are investing in initiatives designed to grow their bioscience sector, states are also passing legislation to limit the cost of prescription drugs or place limits on the use of certain drugs by Medicaid patients. Such policies can have an adverse impact on the very bioscience companies that these states are seeking to develop. Colorado should review the state's Medicaid policies relating to pharmaceuticals to ensure that these policies do not inadvertently discourage the building of the bioscience industry in the state.

Action Four: Strengthen the voice of the bioscience industry in Colorado by forming a unified Bioscience Industry Association. Technology regions across the country have found it extremely important to have membership-driven networking and advocacy organizations that work within an industry or technology sector to address common needs and problems and to build

image and awareness of the industry and related assets. Colorado has two organizations, the Colorado Biotechnology Association and the Colorado Medical Device Association, that represent various components of the bioscience industry. In addition, there are several other organizations, including the Colorado Alliance for Bioengineering, that undertake similar activities such as holding networking events and seeking to promote partnerships between bioscience companies and Colorado universities. The ability of each of these organizations to advocate on behalf of the bioscience sector and to facilitate the intensive networking required to support the growth of the biosciences is constrained by resources. A single, unified Colorado Bioscience Association should be established. The Association should:

- Serve as a clearinghouse for information on the biosciences in Colorado. The association can provide a forum for bioscience companies and academic research institutions to exchange information on issues related to the biosciences and maintain data on Colorado's bioscience industry cluster;
- Advocate on behalf of the biosciences, identifying needs and developing proposals for policies and programs to address these needs;
- Act as a matchmaker and networker—the association can help connect groups and organizations and make them aware of opportunities. It can hold various events to bring higher education and industry representatives together to learn about trends and developments; and,
- Promote the image of Colorado as a center of the biosciences. The industry association can help publicize, inform, and educate the public through the media and through the events and programs it sponsors about the biosciences and its contribution to the Colorado economy.

The economic development community should work with the bioscience industry association in accomplishing these goals.

Action Five: Create a focus on the biosciences within the Governor's Office of Economic Development and International Trade. The Governor's Office of Economic Development and International Trade markets Colorado for business and tourism development and assists companies interested in relocating to or expanding in Colorado. The state has few of the economic development incentive programs that other states use to assist companies directly, with the exception of a job training program that assists companies with customized job training. It is recommended that the state of Colorado undertake a business development effort focused on marketing the bioscience assets of the state and assisting bioscience companies wishing to locate in Colorado. Specific initiatives could include:

- Creating a state-level bioscience marketing team to coordinate participation in industry trade shows, developing lead generation efforts, and responding to inquiries from bioscience companies interested in locating in Colorado;
- Establishing an integrated, statewide, one-stop bioscience company response team that will ensure quick turnaround on permitting, deal packaging, research partners, and other needs of bioscience companies; and,
- Undertaking trade missions focused on domestic and foreign markets that provide opportunities for the biosciences.

Action Six: Develop and implement an industry-led, comprehensive communications strategy to educate and inform citizenry, elected officials, the nation, and the world about Colorado's biosciences. For this bioscience plan to be successfully achieved, various groups and organizations across the state must come together to support its implementation. But, to do this is not easy or simple. The stakeholders will need to be committed to this effort for the long term; states do not build bioscience clusters overnight. And it will require a considerable degree of collaboration and connectivity among the various entities willing to work over many years for the common good of the state.

It is proposed that an industry-led campaign be undertaken to build awareness among state policymakers, business and community leaders, and the state's citizenry of the strengths of Colorado in the biosciences and the benefits to be derived from developing the state's bioscience sector. The bioscience industry association needs to assume a leadership role in accomplishing these goals. Specific actions that should be taken include:

- Engaging in ongoing, continuous dialogue with legislators and opinion makers on the importance of the biosciences and its contribution to Colorado's economy;
- Holding an Annual Bioscience Summit as part of an existing bioscience state event, such as BioWest;
- Organizing delegations to represent Colorado at national conferences, such as BIO; and,
- Undertaking public outreach and educational activities.

Action Seven: The Colorado Institute of Technology should work with industry to identify and address emerging bioscience workforce and education needs at all levels. Existing Colorado bioscience companies indicated in interviews that they are generally able to find workers with the skills they need, although in some cases they must go out of state to recruit senior employees with experience in the biosciences. Some companies indicated that they had difficulty filling some positions such as medical technicians. While workforce does not appear to be a limiting factor at the moment, over time as the bioscience sector grows, there will be need for an increasing number of bioscience workers. Colorado is fortunate to have a highly educated population and an available workforce and educational institutions that will be able to provide the training needed to prepare people to become bioscience workers. The challenge will be to identify skill needs, to develop appropriate curricula, and to establish and fund programs for workers in this rapidly changing field.

In addition to ensuring that current and near term workforce needs are addressed, emphasis must be place on working with industry and the state's research institutions to identify the degrees, programs, and courses that will be needed to position Colorado to grow the state's bioscience niches. Increasingly interdisciplinary and multi institutional programs are required to educate, train, and graduate the future bioscience workforce. Those universities that are quickest to incorporate the results of technological advancements into their curriculum will have a lead in producing the talent needed by bioscience firms, particularly in multi-disciplinary fields that support Colorado's' bioscience competencies.

Colorado's research institutions have begun initiatives, such as the CU Center for Computational Biology, to address some of these needs already. The Center has launched certificate, masters, and PhD. Programs in computational biology, bioinformatics, and computer sciences. For

Colorado to fully leverage its areas of key bioscience research strengths, enhanced capabilities in not only computation biology but in other areas such as bioengineering will be needed.

CIT serves as the central strategic planning entity that is charged with analysis assessing industry needs and higher educational institutions' capacity to respond. It is proposed that CIT work with Colorado's research institutions and industry to identity the degrees, program and courses that will be required to advance this bioscience plan and ensure that funding is available to establish and grow programs like the Center for Computational Biology. The technology platforms that offer the greatest opportunities for growing Colorado's bioscience sector and the programs and educational offerings required to support their development are identified in the core competency report prepared as part of the development of this plan.

Lastly, addressing the bioscience pipeline of future workers also is critical. A focus is required both on K–12 education and on technician-level education in community colleges, two areas from which the bioscience industry traditionally has not drawn it workforce but likely will in the future. CIT should work with the bioscience industry association to identify and address needs for K–12 and technician level education.

Strategy Two: Grow the state's bioscience cluster by creating a bioscience entrepreneurial culture that turns research discoveries into new products and services and cutting edge firms and provides appropriate incentives to research institutions and industry.

Action One: Provide comprehensive in-depth entrepreneurial assistance to bioscience entrepreneurs and companies. One of the goals of Colorado's Bioscience Plan is to grow a critical mass of bioscience companies by encouraging new firm creation. This will require encouraging entrepreneurs and providing support to new start-up companies. Colorado has a number of organizations including industry associations, incubators, the Colorado Bioscience Park Aurora, local economic development organizations, and university technology transfer offices that provide some level of support to entrepreneurs and new start-up companies. These organizations should work jointly to create more in-depth programs for entrepreneurship education, and provide training, coaching and mentoring specifically targeted to bioscience companies. Services to be provided through these programs could include technology and market assessments, providing assistance in applying for Small Business Innovation Research (SBIR) and other grant programs, help in developing a business plan, and help in identifying and accessing sources of capital. The universities' business schools should be further engaged to assist in providing assistance to entrepreneurs and faculty seeking to commercialize research findings and/or interested in starting new ventures.

Action Two: Create a Colorado Bioscience Seed Fund and encourage the formation of bioscience angel capital networks. While Colorado companies in general have a good track record in terms of attracting venture capital, and Colorado bioscience firms have been successful in attracting outside later stage venture capital investment, there is a lack of very early stage seed and pre-seed capital for entrepreneurs and start-up bioscience companies. To address this need, the creation of a Colorado Bioscience Seed Fund is proposed. Such a fund would provide post-angel but pre-formal venture financing in the range of $150,000 to $2 million size investments. It is proposed that the fund be privately managed. Potential sources of capital are private investors, university foundations, and state pension funds. The Fund would target itself to raise $35–70 million for its initial capitalization. To address the need for even earlier, smaller levels of investment, the creation of bioscience angel capital networks should be encouraged.

Action Three: Enact legislation that would use state tax credits to guarantee investments in a fund of funds that would invest in private venture capital companies willing to invest in Colorado companies. Although some Colorado bioscience companies have been successful in obtaining venture capital, the majority of this capital has come from out of state funding sources. Over the long term, it will be important for Colorado to develop additional locally-based venture funds willing to invest in bioscience companies. It is proposed that Colorado enact legislation authorizing creation of a "fund of funds" that will invest in private venture capital funds that commit to investing in Colorado. Money for the fund of funds would come from the sale of stock to institutional investors such as banks and insurance companies, with the preferred stock having guaranteed dividend and redemption features. Tax credits would be used to collateralize the guarantees. Therefore, the credits would be used only if the cash flow from the fund of funds is insufficient to meet the obligations granted in the preferred stock. This proposed program would be similar to one that has been in place in Oklahoma since 1992. (See text box.) Legislation for similar programs has been enacted in Iowa and Utah. One advantage of this approach is that the fund of funds can direct investments to venture capital funds that invest in particular types of companies, such as bioscience companies.

Oklahoma Capital Investment Board

In 1992, Oklahoma created the Oklahoma Capital Investment Board (OCIB) to encourage equity and near-equity investments in private venture capital partnerships. The capital OCIB invests comes from institutional lenders and investors through the Oklahoma Capital Formation Corporation. The principal and interest on OCIB's borrowed funds are guaranteed if necessary by $50 million in tax credits with limits of $10 million of tax credits per year. State tax credits will be used only in the case that investment returns are insufficient to meet OCIB's guarantee commitments. Since its inception, OCIB has invested in eight private limited partnerships investing a total of $26 million. These funds have drawn down $18 million and invested (including co-investors) $66 million in 11 Oklahoma companies. The annual rate of return since inception has been 29.6 percent.

Types of Capital Needed by Bioscience Firms

- *Commercialization funding,* **which can be used to assess and undertake a review of the commercial potential of completed R&D.**
- *Pre-seed and seed funding,* ***i.e.*****, financing to support very early stage start-up companies.**
- *Venture financing*, **which is the capital needed prior to initial public offering. Given the long time frame required for the regulatory review process, bioscience firms will often require multiple rounds of venture financing.**

In addition, it is proposed that legislation be introduced to provide state tax credits to individuals that invest in Colorado based bioscience-focused seed and later stage venture funds. In light of the state's current fiscal situation, the tax credit would be triggered at a predetermined point as the state's fiscal situation improves.

Action Four: Undertake activities that recognize successful bioscience role models. One lesson from successful bioscience regions is that role models and entrepreneurial success stories are key parts of winning efforts to build entrepreneurial cultures. If Colorado wants to develop its bioscience cluster by growing its own bioscience companies, it will be important to convey to its citizens the opportunities presented by the biosciences and the success that has been and can be achieved by bioscience entrepreneurs. Colorado has a number of industry association and development organizations that seek to promote and build awareness of the biosciences in Colorado. The Colorado Biotechnology Association, Colorado Medical Device Association, Colorado Venture Centers and the Fitzsimons Redevelopment Authority, for example, hold monthly BioBreakfasts that provide opportunities to showcase bioscience companies. In October 2002, the first BioWest conference was held, which also provided an opportunity to highlight Colorado bioscience company success stories. These efforts should be continued and expanded. It is also proposed that a **Colorado Bioscience Entrepreneur of the Year Award** be established to reward and encourage successful bioscience entrepreneurs who will become the roles models for the next generation. A Colorado Bioscience Entrepreneur of the Year award will also promote the importance of the biosciences to Colorado's economy.

Action Five: Explore opportunities to establish plant and animal-based pharmaceutical and nutraceutical production within Colorado. Colorado has been identified as a target market for ag-biotechnology for the production and processing of transgenic crops genetically engineered to produce pharmaceuticals and nutraceuticals. Recent advances in technology which enables genes for specific drugs to be inserted into major agricultural crops opens the possibility for revolutionary change in pharmaceutical and specialty chemical production. Using plants to produce drugs offers the possibility of greatly reducing the cost of transgenic drugs. Despite the opportunities this poses, there are also significant production related issues that arise with the movement of the production of active pharmaceuticals from a carefully controlled environment to an uncontrolled outdoor environment. A number of communities in Colorado are already investigating opportunities for plant and animal pharmaceutical and nutraceuticals production. Elbert County, for example, has produced an Opportunity Assessment Plan and Adams County is also pursuing a similar initiative. It is recommended that Colorado move quickly to assess opportunities and develop an action plan to position Colorado to take advantage of this emerging bioeconomy.

Boston University's Community Technology Fund

The Community Technology Fund (CTF) is Boston University's (BU) name for its combined licensing office, commercialization function, and direct-investment fund. A separate unit of CTF, called "New Ventures," is responsible for developing new start-up companies based on BU technologies.

New Ventures makes "technology development awards" that are designed to "bridge the gap between government funded basic science and the more developed technologies that are of interest to commercial entities." The grants, which range from $20,000 to $50,000 but can be up to $100,000 under special circumstances, can be used to finance commercialization research or reduction to practice. Projects are selected based upon commercialization potential and the feasibility that the award will increase the value of a technology or the likelihood that it will be commercialized. The awards are not repayable.

Action Six: Continue to build and strengthen technology transfer/commercialization capacity of universities. It is generally acknowledged that in the past, Colorado's universities have not emphasized technology transfer and commercialization. Despite this fact, a number of Colorado's successful bioscience companies have been founded by faculty and researchers from the universities. But during the last two years, the Colorado School of Mines, Colorado State University and the University of Colorado have each strengthened their commitment to technology transfer. In 2002, the University of Colorado system developed its first ever Strategic Plan for Technology Transfer, which sets a goal of being recognized as the best technology transfer office among public universities by 2010. The Colorado State University Research Foundation is implementing a Strategic Plan for Technology Transfer that was adopted in 2000. The universities should continue to emphasize the importance of commercializing research findings and provide the necessary support needed to operate effective technology transfer operations.

Action Seven: Create Technology Development Funds to support proof of concept and other commercialization activities. It is recommended that Technology Development Funds be established within each Colorado research institution that would provide financial support to ascertain the commercial potential of research findings and to move research toward commercial applications. The fund would provide funding in the range of $25,000 to $100,000 to undertake due diligence to determine commercial potential. This level of funding is needed to bridge the gap between basic science conducted at Colorado's research institutions and the development of technologies with commercial potential. The fund would make awards to be used to increase the value of a technology and to develop it to the point at which its commercial potential has been demonstrated. Awards could be used to develop a prototype or conduct further research that helps determine market value. The funds could seek contributions from alumni, foundations and high net worth individuals.

Strategy Three: Expand the research base and build research excellence in the state's bioscience niches.

Action One: Complete full physical development of UCHSC/UCH Fitzsimons Campus to help anchor Colorado's bioscience research base for the future. The State of Colorado and the University of Colorado have committed to relocating UCHSC and UCH to a state of the art medical campus at Fitzsimons. The Children's Hospital is also relocating to the campus from its current location in Denver. The campus on which the University and hospitals are located is linked to the 160 acre Colorado Bioscience Research Park Aurora, which will house university-affiliated and emerging bioscience companies. The Fitzsimons site provides the opportunity to create an interactive community of bioscience research, teaching and patient care.

The initial phase of the move of UCHSC and UCH to Fitzsimons is estimated to cost $1.3 billion, which will result

There is great anticipation of an influx of positive economic growth...The combination of UCHSC/UCH and a huge bioscience research park will bring industry to the area. It will be a transfer between the basic sciences and the practical world."

James H. Shore, MD, Chancellor, University of Colorado Health Sciences Center

in an increase from 2.7 million gross square feet on 46 acres at the current location to 3.4 million gross square feet on 217 acres at the new location. Another 1.5 million gross square feet of space, mostly for research is slated for construction following the initial transition period.[12] Completion of the entire Fitzsimons building program will require a total capital investment of nearly $4 billion.

The university has proposed that the state issue Certificates of Participation (COP) to fund the completion of its portion of the Fitzsimons academic development, which totals $202 million.[13] The COP would be issued for $202 million over 25 years, requiring a $15.1 million annual contribution from the state. Funding for the $15.1 million would come from a variety of sources. Legislation to authorize the COP for Fitzsimons is currently under consideration by the Colorado legislature. Enactment of this legislation will help move forward the development of the Fitzsimons campus, a key component in advancing the development of Colorado's bioscience cluster.

While the location of the UCHSC/UCH campus at Fitzsimons is a key anchor, Colorado should work with its Congressional delegation to identify opportunities for federally supported facilities to locate at Fitzsimons. One facility already identified is the VA Medical Center. The relocation of the VA Medical Center to Fitzsimons should continue to be pursued as it would provide another important anchor for the campus and would be a key component in the network of institutions providing patient care, biomedical research, education and biotechnology R&D at the Fitzsimons site.

Action Two: Encourage collaborative partnerships between academic researchers and industry by providing funding for collaborative university/industry applied research projects, streamlining industry contracting, and designating an industry liaison.

As discussed above, it is commonly acknowledged that Colorado's universities do not have a strong history of collaborating and connecting with industry. For Colorado to become a leading bioscience center, it needs to build sustained relationships between its bioscience companies and the state's research institutions. One way to accomplish this is to provide funding for collaborative university/industry applied research projects. Such projects help build relationships between researchers and companies and provide support for activities that help to move technology to the point where private investment capital can be obtained.

At least a dozen states have matching grant programs that provide an incentive for firms to support research projects at local research institutions. One such program is Utah's

BioSTAR

An excellent example of an industry/university matching grant program in the biosciences is the University of California's Biotechnology Strategic Alliances in Research (BioSTAR) program. Established in 1996, this mechanism links life science companies with researchers in their field through a modest matching grant. BioSTAR involves a highly competitive process in which research proposals are peer reviewed and companies must provide at least half the cost of the project. Since its inception, BioSTAR has fostered linkages between many of California's small, emerging, life science companies and the University of California campuses, providing a highly valuable competitive edge to its emerging, small, life science companies.

[12] http://www.uchsc.edu/fitzsimons/

[13] Under this proposal, the state would enter into lease-purchase agreements to build capital facilities. If approved, the state's annual lease payments will be marketed to investors as certificates of participation. A "certificate" refers to an investor's proportionate interest in the state's lease payments.

Centers of Excellence Program. The Utah program is somewhat misnamed as it is really a project grant program, not a centers program. Nevertheless, it represents an example of a challenge grant program intended to create enduring academic/industrial partnerships that lead to ongoing support and commercialization of intellectual property within the state. Budgeted at about $2 million a year, the Centers program supports about 15 projects at any one time, with allocations up to a maximum of $200,000 per project. The program supports faculty at Utah universities, helping them to advance the research program in a way that attracts interested industrial partners from within the state. State funding must be matched by industrial partners. Since 1986, a total of nearly 80 projects were funded at a cumulative investment of $832 million, matched 10:1 by funds from industrial partners. The Center program is credited with the creation of 150 new companies and 204 license agreements. Another program designed to promote industry universities partnerships that is focused exclusively on the biosciences is California's BioStar program, which is described in the text box.

National best practice suggests that matching grant programs are the most effective method when compared with other types of university/industry partnerships that exist to promote technology commercialization. Another approach to providing funding for higher education/industry partnerships is to use tax credits to build stronger and more sustained relationships between state industries and research institutions. It is proposed that Colorado create a project matching program or R&D voucher program that would provide funding for industry research projects conducted by Colorado research institutions. It is proposed that funding be provided in the range of $125,000–$250,000. The industry partner must match the state funds on a 3:1 basis. The annual budget for this program would be approximately $2–$2.5 million annually.

Another action that the universities can take to encourage more collaborative research with industry is to streamline industry contracting procedures and make them more user friendly. Lastly, there is a need to continue dialogues to build greater understanding on the part of faculty of industry needs and requirements and on the part of industry of university missions and requirements. The Colorado Biotechnology Association should take the lead in helping industry to learn how to access and partner with universities. For their part, each of the research institutions need to commit to being responsive to industry requests. It is recommended that each research institution designate an industry liaison to serve as an initial point of contact for industry wishing to find industry researchers with which to interact.

Action Three: Identify opportunities and compete for national and federal institutes and centers of excellence in bioscience niche areas. Increasingly states, through their public and private representatives, have been working closely with their Congressional Delegations to ensure federal investments are made that help create the research and research infrastructure anchors that help build bioscience economies. As noted in the description of best practices, one key lesson for state and regions building a bioscience economy is the importance of federal funds for federally-designated centers and institutes, whether the funding comes in the form of operating or capital funds. Almost every major mature bioscience region or state in the U.S. has one or more federal anchors that have contributed to building its bioscience base, e.g., NIEHS in Research Triangle Park, Lincoln and Draper Labs in Boston, and NIH in Maryland. Discretionary federal funding unfettered by federal mission also plays a role in enabling exploratory research to be undertaken that may lead many years later to applications in various bioscience areas.

In order to develop research excellence in selected areas, Colorado's research institutions will have to come together to collaboratively pursue opportunities for federal and other sources of research funding. A good example of where this has happened recently is the proposal that has been submitted to the National Institute of Allergy and Infectious Diseases for a regional center of excellence in bioterrorism and emerging infectious diseases by a coalition of regional research institutions led by CSU and the CDC laboratory in Fort Collins.

Action Four: Develop a pilot program of product development and technical assistance support for the medical device, advanced manufacturing and bioagriculture development industries. One potential way to bring firms, particularly small and medium sized device firms, into closer contact with research organizations is by forming a pilot demonstration program whereby a product development/technical assistance center can be established at one of the University campuses in Colorado. Alternatively, the bioprocessing scale up facility at CSU could be used to house such a center. This effort should be undertaken as a pilot project to determine whether such a center would be effective in creating relationships and communications between industry and academe. If successful, additional pilot centers serving other industries can be considered or the pilot program could be expanded and made permanent.

IMPLEMENTATION PLAN

Colorado is well positioned to grow its bioscience cluster. But if Colorado is to succeed in capturing significant growth in this sector, it must act quickly as other states and regions are aggressively making investments to attract and grow their bioscience sectors. If Colorado is to achieve its vision for the biosciences, it must rapidly implement the strategies and actions in this plan.

This plan has been developed with the support of the State of Colorado, Colorado's bioscience industry, the state's research institutions, and economic development organizations. Each of these stakeholders has a role to play in implementing the plan. But it is also important that one entity take responsibility for coordinating the efforts of the various players and monitoring progress. It is recommended that the management team that developed the Plan and the state's Bioscience Advocate play this coordinating and monitoring role. It is further proposed that the bioscience industry, through the Bioscience Industry Association, take lead responsibility for implementing the Plan and leveraging other stakeholders to take responsibility for key elements of the plan.

In addition to the Colorado Bioscience Industry Association, key stakeholders responsible for implementing various actions include:

- Governor's Office of Economic Development and International Trade;
- Colorado's research institutions, with leadership from the University of Colorado and Colorado State University;
- Colorado's economic development organizations, with leadership from the Metro Denver Chamber of Commerce and other chambers and economic development organizations throughout the state; and,
- Colorado Institute of Technology.

It is recommended that each of the stakeholders identify and commit to implementing the actions appropriate to their organization.

Priority Actions

In light of the economy and the current fiscal condition of the state, it is important to identify those actions that are likely to have a direct impact on the development of Colorado's bioscience sector. It is recommended that the following actions be undertaken immediately.

1. Appoint Bioscience Advocate within state government.
2. Continue to build and strengthen technology transfer/commercialization capacity of universities, including creating technology development, proof of concept funds.
3. Complete development of UCHSC/UCH Fitzsimons Campus.
4. Strengthen the voice of the bioscience industry in Colorado by forming a unified Bioscience Industry Association.
5. Create a privately managed Colorado Bioscience Seed Fund and encourage creation of bioscience focused angel investor networks.
6. Explore opportunities to establish plant-and animal-based pharmaceutical production within Colorado.
7. Create a focus on the biosciences within the Governor's Office of Economic Development and International Trade.
8. Develop and implement an industry-led, comprehensive communications strategy.

Measures of Success

It is recommended that the following measures be used to gauge success and progress in implementing Colorado's bioscience plan:

- Increase in bioscience R&D funding at Colorado research institutions equal to or greater than the national average.
- Increase in industry funding of bioscience R&D at Colorado research institutions to the national average for industry funding as a percent of total R&D funding.
- At least $100 million in federal and other bioscience dollars attracted to Colorado for centers and national institutes by 2008.
- Increase commercialization of bioscience technology developed at Colorado research institutions as measured by number of new start-ups and number and value of licenses.
- Growth in state's bioscience economic base: number of firms, their employment, their concentration in the state relative to the nation, and birth and death rates of firms.
- Indigenous venture capital dollars invested in Colorado bioscience companies will reach $50 million by 2008.
- Implementation progress on the actions laid out in the plan of at least 70 percent with substantial action after three years, and 90 percent within five years.

CONCLUSION

Colorado is fortunate to possess strong assets in the biosciences that offer great potential for the state's economy. To date, the state's bioscience sector has developed largely by serendipity and if left alone would be likely continue to grow somewhat. But this sector has the potential to become a true driver of Colorado's economy.

Taking advantage of the opportunities provided by the biosciences in Colorado will require:

- Commitment and willingness to collaborate on the part of the public, private and academic communities;
- Achieving research excellence with national level focus in selected areas;
- Commitment on the part of Colorado's universities to a broad commercialization program to capitalize on technology transfer and entrepreneurial activities;
- Continued investment in bioscience infrastructure, including the completion of the Fitzsimons development; and,
- Commitment on the part of the State of Colorado to support the bioscience sector.

In the early years of the New Millennium, the biosciences have emerged as one of the most dynamic and growth-oriented sectors of the economy. Advances in the biosciences will likely revolutionize the economy of the coming decade, as telecommunications and computer technology did in the prior decade. Colorado has the opportunity to seize the opportunity presented by the biosciences and build an industry that will not only have economic development benefits but that can improve the health and well being of Colorado's citizens.

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Introduction

In the early years of the New Millennium, the biosciences have emerged as one of the most dynamic and growth-oriented sectors of the economy. Advances in the biosciences will likely revolutionize the economy of the coming decade, as telecommunications and computer technology did in the prior decade. The bioscience sector is unique in its inherent diversity, combining activity and expertise from biology, agriculture, medical sciences, public health, organic chemistry, engineering, and computer science, among other fields.

Today the bioscience sector is at the forefront of creativity and innovation. Following the successful completion of the Human Genome Project, a new era of innovation is being unlocked, creating new arenas of research and application from bioinformatics to proteomics, combinatorial biology and personalized medicine. At the same time, progress in microelectronics, robotics, biomaterials, and nanotechnology is establishing new avenues for advancements in medical devices, drug delivery, and surgical practices.

In 1999, Colorado created the Governor's Office of Innovation and Technology (OIT) whose mission is to make Colorado a world leader in the formation and implementation of technology. During the last four months, OIT, assisted by a management team that included industry, university and government representatives and with support provided by Battelle Memorial Institute's Technology Partnership Practice, has assessed the current status of Colorado's bioscience sector and has sought input from leaders of the state's research institutions, researchers, entrepreneurs, CEOs of bioscience companies, economic development organizations, and other service providers to determine what needs to be done to ensure that Colorado is fully realizing the opportunities provided by the revolutionary changes occurring in the biosciences.

Bioscience Action Plan Methodology

- Economic analysis
- Core competency analysis
- Benchmarking analysis
- SWOT review
- Interviews of academic, business, and community leaders
- Focus groups and discussions

This report includes:

- A discussion of the role the biosciences could play in Colorado's future technology economy.
- An economic analysis of the current strengths, dynamics, and changes in Colorado's bioscience industry base.
- An assessment of Colorado's bioscience research base that identifies areas of existing and emerging areas of bioscience research strengths.
- An assessment of Colorado's competitive position vis-à-vis other states that have or are trying to develop their bioscience sectors on the key factors needed to support the development of the biosciences.

- A situational analysis that reports findings based on interviews with many of the state's public and private sector leaders in regard to strengths, weaknesses, opportunities, and threats (SWOT) facing Colorado in its effort to position itself in the biosciences.
- Proposed strategies and actions to make the biosciences an important contributor to Colorado's technology economy.
- An implementation plan that outlines initial steps that need to be taken to execute the action plan.

COLORADO'S BIOSCIENCE FUTURE

In recent years, Colorado has succeeded in growing the state's technology economy, particularly capturing growth in the telecommunications sector. But a brief look at Colorado's economic history suggests that the state needs to continue to diversify its technology economy. In part, this can be achieved by nurturing the state's existing bioscience sector.

Colorado's Economy

Colorado's economic history has been one of boom and bust. Statehood was in fact catalyzed by the economic boom generated by the discovery of gold. Although the discovery of gold was not long sustained, the mining industry continued to be the dominant sector through the end of the century. When the depression of 1893 and the repeal of the Sherman Silver Purchase Act abruptly ended the state's first boom, civic leaders recognized the need to diversify the economy, and turned to agriculture, manufacturing, tourism, and services. As a result, the economy grew steadily, although more slowly, through much of the first half of the twentieth century.

The next significant boom came when Colorado became home to numerous regional and national headquarters of oil and gas firms after World War II. However, during the 1980's oil bust when the price of crude oil dropped from $39 to $9 a barrel, the state sank into a severe recession. State government responded by creating the Colorado Advanced Technology Initiative (CATI), funding the Economic Development Commission, adding a business development office, and developing several public sector infrastructure projects.

As the 1990s began, the Colorado economy began to recover and outperform the national economy. By the end of the decade, Colorado was again in a significant boom cycle. The state's population was consistently growing two and a half times faster than the national growth rate. In addition, between 1992 and 1998 Colorado had the fifth fastest growing gross state product in that nation, with an average 6.6 percent annual growth rate. Much of this new growth was spurred by information technology (hardware and software) companies. By 2000, Colorado placed first in the nation in the concentration of high technology workers.

Significant progress was made across the state in growing the technology sector throughout the 1990s. Colorado Springs was endowed with an abundance of high-tech workers due to important military institutions including the North American Space Command at Cheyenne Mountain and the U.S. Air Force Academy. The city ranked as the national leader among the country's mid-sized metros (population 500,000 to one million). While the metro did not serve as the headquarters city for major high-tech industries, it was home to large branch plants of Apple,

Digital Equipment, and Hewlett-Packard. In addition to computer manufacturers, the city also saw a burgeoning software and computer systems design industrial growth through the 1990s.

The Fort Collins-Loveland metro area became one of the most high-tech places in the country for its size (population 200,000 to 500,000) during the 1990s. Fort Collins was home to the technological innovation of Colorado State University as well as large Hewlett-Packard and Agilent Technologies plants, as well as a significant number of computer systems design companies.

The Denver-Boulder Greeley metro area also emerged as one of the country's high-tech leaders in the 1990s. While many factors contributed to this status, including the location of the University of Colorado, it was Denver's long-standing presence in a variety of high-tech industries that really spurred the development during the decade. Storage Tech and IBM had large data storage facilities. Several large telecommunications firms, with large numbers of workers in high-tech occupations, also were headquartered or had large facilities in the metro region. Among very large metro areas, only the San Francisco Bay area ranked higher than the Denver-Boulder-Greeley on the number of high-tech workers.

However, the boom of the 1990s ended in bust at the turn of this century with the collapse of the dot.com phenomena and the significant downturn of the IT sector. The state has been affected by the same factors that caused the national downturn in the IT industry. However, since Colorado had a higher than average concentration in this sector, its economic impact has been more severe.

Just as civic leaders recognized at the turn of the last century that the state needed to diversify its industrial base beyond mining, so too must the leaders of this century seek to diversify in today's rapidly changing technology-based economy. While the IT industry can be expected to rebound once the national economy recovers, Colorado also needs to develop other technology sectors, most particularly biosciences, to sustain its future development, offering jobs and contributing to a healthy citizenry, too.

Table 1: Colorado Average Annual Employee Earnings

Sector	Amount ($)
Industrial Machinery	$65,064
Research and Testing	64,331
Drugs and Pharmaceuticals	54,473
Medical Devices	47,018
Aerospace	46,505
Organic and Agricultural Chemicals	42,423
Metals	41,349
Rubber and Plastics	38,935
Entire private sector	37,553
Construction	36,967
Motor Vehicles	34,511
Hospitals and Laboratories	33,620
Note: Dollar amounts are real 2000 dollars. Source: *Covered Employment and Wages (ES-202),* Bureau of Labor Statistics, 2000.	

WHY DEVELOP THE BIOSCIENCES IN COLORADO

The bioscience sector[1] is a rapidly growing, global industry characterized by scientific and technological innovation and discovery. It involves a collection of industries with a wide variety of applications ranging from life saving drugs to cleaner bio-engineered fuels, from new medical imaging devices to healthier foods, from mapping the human genome to safeguarding against bio-terrorism. There are a number of reasons for seeking to develop Colorado's bioscience sector.

The bioscience sector offers the opportunity to create high wage, skilled jobs for Colorado residents, thereby creating wealth for Colorado citizens. Colorado wage information indicates that jobs created in the bioscience industry are among some of the highest paying jobs within the state. Table 1 presents annual average employee wages received in 2000. All four subsectors of the bioscience sector exceed average annual earnings for the entire private sector. Research and testing (biotechnology) offers the highest annual wage of all the bioscience subsectors. Research and testing is also the fastest growing subsector in the state, indicating a significant opportunity for the state to foster wealth creation by encouraging the growth of this fast paced subsector. Medical devices is another high paying subsector in the state that possesses a significant presence in terms of its employment size and significance.

The bioscience sector offers a broad range of jobs requiring a variety of skills and education. The broad range of occupations that biosciences support is often not recognized. The biosciences offer abundant employment opportunities over the entire range of education and experience levels, from research scientists and medical doctors to technicians, laboratory researchers, and manufacturing workers. Contrary to public perceptions, the largest share of employment in the biosciences nationally consists of production and technician positions—accounting for more than 50 percent of employment in medical device industries, more than 40 percent of pharmaceutical employment, and more than 30 percent of workers within the organic and agricultural chemicals industries.[2]

The biosciences is a high growth sector. The bioscience sector of the economy is large, fast growing, diverse, and crosscutting. It involves a wide range of manufacturing, service, and research activities. Industries involved in the biosciences range from pharmaceutical development to agricultural production, from medical device assembly to biological research and testing. Moreover, the recent surge of advances in the field suggests great potential for rapid growth of new bioscience firms.

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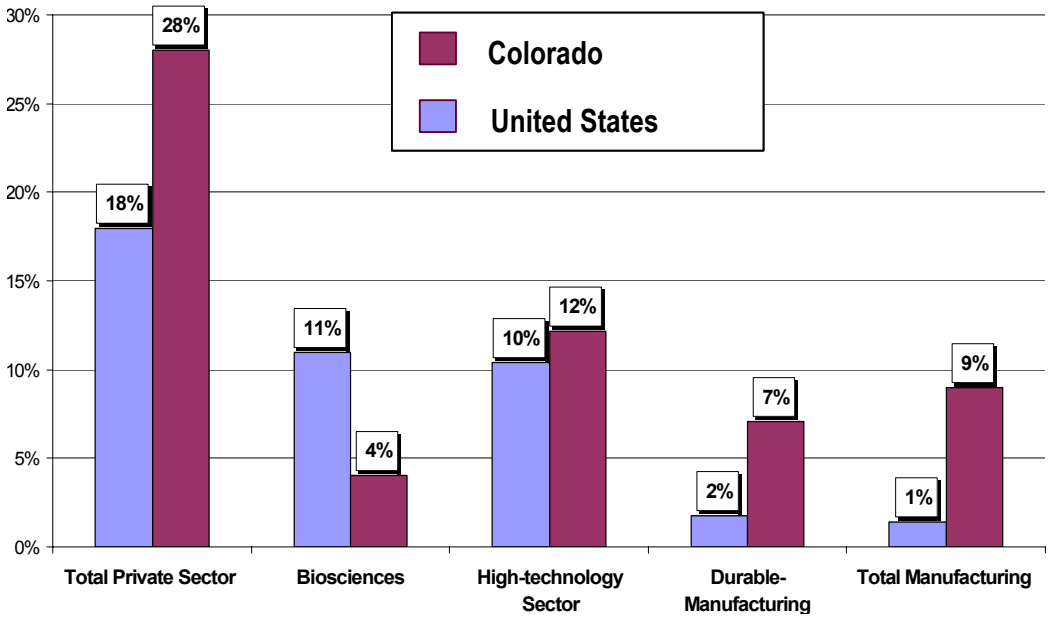
[1] In this report, the term "biosciences" refers to a relatively broad range of biological and life-sciences-related activity including drugs and pharmaceuticals, agricultural and organic chemicals, medical device and instrument manufacturing, and bioscience research and testing. The data on employment and establishments are taken from Dun & Bradstreet's *MarketPlace* survey.

[2] Calculated from Occupational Employment Statistics, Bureau of Labor Statistics, 2000.

Nationally the bioscience industry has experienced employment growth that has surpassed increases in other sectors of the economy. Over the past four years, bioscience industries[3] have grown by 11 percent, adding 120,679 jobs nationally. During the same time period, the high-technology sector, which includes the biosciences, grew 12 percent nationally and manufacturing grew only one percent (see Figure 1).

Figure 1: Employment Growth 1998–2002



Colorado's high technology sector grew even faster than that of the nation growing by 12 percent between 1998 and 2002. While the bioscience sector in Colorado only grew by four percent in employment during this time period in comparison to a national increase in employment of 11 percent, the research and testing (biotechnology) component of the biosciences grew 95 percent in Colorado in comparison to a 35 percent growth rate nationally. Colorado has the opportunity to capture a greater share of the nation's growth in the biosciences, a sector that is expected to continue to experience significant growth.

The bioscience sector can bring stability to Colorado's economy. As an economic driver, the diversity of the bioscience sector ensures relative stability. Because demand for medical-related and food products remains fairly constant year after year, development of the biosciences provides insulation against the ups and downs of business cycles.

The biosciences is a renewable industry sector, i.e., the industry is dynamic. Talent and companies churn and firms continue to develop products and applications for technologies on an ongoing basis. Studies of the evolution of existing bioscience centers, such as San Diego and Maryland, show that as bioscience companies succeed they tend to spawn new companies. In some cases, firms will be acquired and the original founders will move on to start other companies. In other cases, employees will leave successful companies to start ventures of their own. In San Diego, more than 45 firms trace their lineage to a single bioscience company,

[3] Bioscience industry includes drugs and pharmaceutical, organic and agricultural chemicals, medical devices and instruments, and research and testing.

Hybritech.[4] A recent study of founders of Maryland bioscience and medical instrument companies found that "the growing maturity of the bioscience/biomedical sector in Maryland has allowed it to begin to perpetuate itself through spin-offs of subsidiaries/affiliated companies, spin-outs of employees eager to run their own businesses, and 'serial entrepreneurship' by several individuals who have built and sold a series of companies."[5] Colorado not only has a base of emerging bioscience companies with the potential to generate additional firms and products as they mature but established companies such as Amgen, that are already generating additional activity in the biosciences.

The bioscience sector can contribute to the growth of Colorado's other technology sectors, such as information technology, photonics, and advanced manufacturing. The biosciences is unique in its inherent diversity, combining activity and expertise from biology, agriculture, medical sciences, animal sciences, public health, organic chemistry, engineering, and computer science, among other fields. This diversity places the bioscience sector at the center of the technology economy, serving as a focal point for the continuing convergence of technologies. The bioscience industry is increasingly interacting with other technology sectors—such as electronics, information technology, optics, and agriculture. Applications and spin-offs from the biosciences may indeed help boost other Colorado technology-based industries, such as advanced manufacturing and information technologies.

Examples of Colorado companies linking biosciences and photonics sectors:

- **Hamamatsu:** develops and manufactures equipment for biomedical imaging.
- **PhotoSense, LLC:** a development stage company bringing innovative non-invasive optical sensing technology to medical, industrial and environmental applications.
- **Hach Company:** provides advanced analytical systems and technical support for water quality testing, with solutions for lab, process, and field. The company uses advance optical analytical instruments.

Colorado has a significant foundation on which to build a bioscience cluster. Colorado has a significant bioscience research base at the state's institutions of higher education and other major non-state institutions that is growing rapidly. Colorado's total bioscience research funding reported by the NSF grew 31 percent from FY 1996 to FY 2000, compared to 27 percent for the nation. In the past five years, funding for the University of Colorado Health Science Center (UCHSC) has nearly doubled from $150.5 million to $249.6 million, with an average growth of 14.2 percent per year during this five year period. For the same period, Colorado State University's (CSU) research funding in its Colleges of Veterinary Medicine, Agricultural Sciences, and Natural Sciences Resources grew from $67.8 million to $109.5 million, representing an average increase of 12.3 percent per year.

[4] Innovation Associates. *Developing High-Technology Communities: San Diego*. Washington, D.C.: Office of Advocacy, U.S. Small Business Administration, March 2000.
[5] Marsha R. B. Schachtel and Scott R. Heacock. *Founders of Maryland Bioscience and Medical Instrument Companies*. Maryland Department of Business and Economic Development and Maryland Technology Development Corporation, August 2002.

Colorado has a growing base of bioscience companies. In 2002, the state had employment of 17,681 across 604 establishments in the biosciences. Between 1995 and 2002, the number of bioscience establishments in Colorado grew slightly faster than the U.S., increasing by 35 percent compared to 29 percent at the national level. During this same time period, employment in Colorado's bioscience sector increased by four percent.

Colorado Bioscience Sector

• **Establishments**	**604**
Percent Change '95–'02	*34.5%*
• **Employment**	**17,681**
Percent Change '95–'02	*4.3%*
• **Percent of private sector employment**	**0.76%**
U.S. percent share of private sector employment	*0.88%*

Colorado has a strong record of venture capital investment that will enable bioscience companies to expand and grow in Colorado. Lastly, Colorado has educational institutions that can produce graduates with the skills and education needed to meet the diverse needs of the bioscience industry.

Developing the bioscience R&D base of Colorado's medical research institutions will lead to high quality health care for Colorado's citizens. Bioscience discoveries are leading to new possibilities for the diagnosis and treatment of a wide range of diseases. Breakthroughs in genomics will soon allow scientists to tailor treatments to specific diseases in specific individuals. It is estimated that within 20 years designer drugs will target specific genetic variations in diseases. Colorado has the opportunity to create an interrelated system of bioscience research, teaching and patient care that builds on its existing hospitals and research institutions to provide state-of-the art health care to its citizenry.

In order to determine what it will take to make the biosciences a key driver of Colorado's economy, it is first necessary to take a look at the current status of the state's bioscience industry. The next section of the report describes Colorado's existing bioscience industry base, its composition and growth trends.

Colorado's Bioscience Industry

The Bioscience Sector

Bioscience is a knowledge-based industry cluster that is constantly altered and reinvented as scientists, engineers, and researchers gain new insights into the ways living organisms function. It is an industry with roots in academic and clinical discovery that take shape in products used in everyday life. This explains in part the reason that public officials, private investors, and academic scholars have watched developments in bioscience with intense interest.

The industry's ability to continually reinvent itself is an indicator of the potential that the biosciences have to spur new economic activity. The implication of new life altering discoveries is the reason bioscience has become such a high value adding industry segment. New market opportunities emerge as new breakthroughs and discoveries are advanced.

The inherent diversity of the bioscience sector is another strong factor contributing to the growing industry focus. The cross cutting technologies embedded in the biosciences has lead to many companies in associated technologies, from precision machining to optics to advanced materials, contributing to life science activities.

The United States is a world leader in many areas of bioscience endeavors—bioscience research, designing and producing bioscience technologies, agricultural and food commodities, medical devices and laboratory instrumentation, drugs, and surgical procedures. Since interactions between researchers and practitioners are vital for continued advancement and progress within the sector, the biosciences have tended to concentrate in certain regional economies in the nation. Nevertheless, many other areas are supporting substantial centers of bioscience activity and engaging in efforts to promulgate, support, and enhance this most promising industry sector.

The state of Colorado has the potential to make its bioscience sector a key contributor to the state's technology economy. Understanding the national market that the biosciences operate in is imperative for the future success of the industry in the state of Colorado. The opportunity exists to support current emerging subsectors in the bioscience industry and reinforce existing specializations.

This economic analysis explores the current position and contributions of the bioscience sector to Colorado's economy. The analysis also identifies emerging and existing subsector strengths in the state and its metropolitan regions, areas that can provide opportunities for future growth of the sector within the state.

Definitions

Currently there is no commonly accepted definition of the "bioscience" industry. Academics and practitioners include varying industrial classifications in their definitions. Categorization is difficult due to the diversity of bioscience activity. The industry is dynamic and encompasses a wide variety of industrial applications. Continual innovation further complicates the industry definition. Bioscience advancements are constantly being applied in new and different ways,

creating new industry segments such as bioengineered agricultural foods or MEMS (microelectromechanical systems)/nano-technology therapies.

Four major subsectors of bioscience activity were identified for this economic analysis. The four categories are:

- Drugs and Pharmaceuticals
- Organic and Agricultural Chemicals
- Medical Devices and Instruments
- Research and Testing (Biotechnology)

Unfortunately, the Standard Industrial Classification (SIC) code does not have a category that encompasses the wide variety of bioscience activity. A list of four- to eight-digit SIC industries were selected according to the four major categories. Table 2 demonstrates the selected SIC codes.

Nevertheless, it is possible that enclaves of economic activity remain that are related to the biosciences but not included in this list. In part, this reflects the inadequacy of the current industrial classification code to categorize bioscience activity. It is also symptomatic of the convergence precipitated by the diversity and spread of the bioscience sector.

Table 2: SIC Industries

INDUSTRY SUBSECTORS	SIC Codes
Drugs	
Medicinals and botanicals	2833
Pharmaceutical preparations	2834
Diagnostic substances	2835
Biological products except diagnostic	2836
Organic and Agricultural Chemicals	
Industrial organic chemicals, n.e.c.	2869
Nitrogenous fertilizers	2873
Phosphatic fertilizers	2874
Fertilizers mixing only	2875
Pesticides and agricultural chemicals, non-fertilizer	2879
Medical Devices and Instruments	
Pharmaceutical machinery	3559-9922
Laboratory apparatus and furniture	3821
Analytical instruments	3826
Surgical and medical instruments	3841
Orthopedics, prosthetics, and surgical appliance	3842
Dental equipment and supplies	3843
X-ray apparatus and tubes	3844
Electromedical equipment	3845
Research and Testing	
Biological research	8731-01
Medical research commercial	8731-9902
Noncommercial biological research organization	8733-01
Food testing service	8734-9903
Seed testing laboratory	8734-9908
Veterinary testing	8734-9910

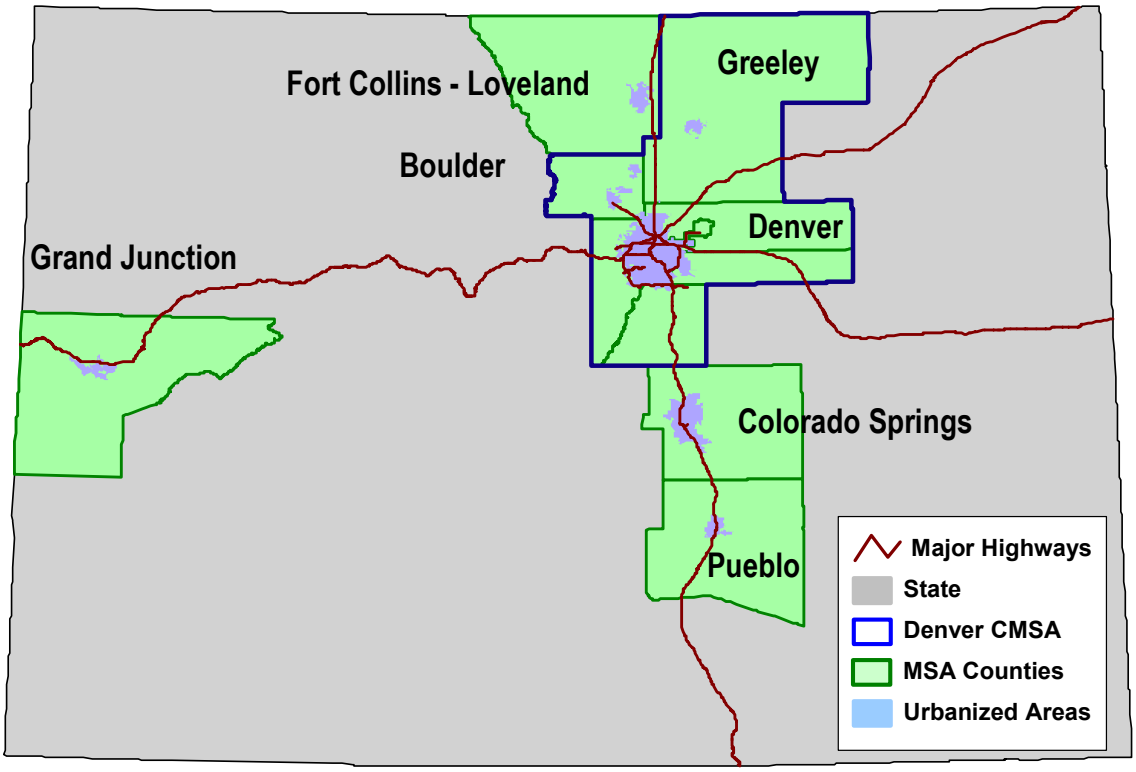
Data and Methodology

The economic analysis primarily examined employment and establishment information obtained from the *MarketPlace* survey administered by the Dun & Bradstreet Corporation. The survey is performed on a quarterly basis. The data were taken from the fourth quarter of 1998 and third quarter of 2002.[6] Supportive data sources were also used. The state of Colorado Department of Labor supplied Battelle with Covered Employment and Wage (ES-202) data for the first quarters of 1992, 1997, and 2002. These data were used to analyze establishment data, wage information and verify employment data. Additional establishment detailed data was collected using the *CorpTech* database produced by OneSource Information Services Incorporated. Corporate and industry information was also gathered from company websites.

[6] The fourth quarter 2002 data had not been released at the time data was collected. Since only portions of the survey are updated in any particular quarter, the data should not vary by quarter in any systematic fashion. This analysis refers to years only.

The information collected from the *MarketPlace* database was gathered for the state of Colorado and the seven Metropolitan Statistical Areas (MSA) contained within the state. According to the United States Census Bureau, the seven MSAs are Boulder-Longmont, Colorado Springs, Denver (which includes Aurora), Fort Collins-Loveland, Grand Junction, Greeley, and Pueblo. Figure 2 identifies the seven MSAs.

Figure 2: State of Colorado and Associated Metropolitan Statistical Areas



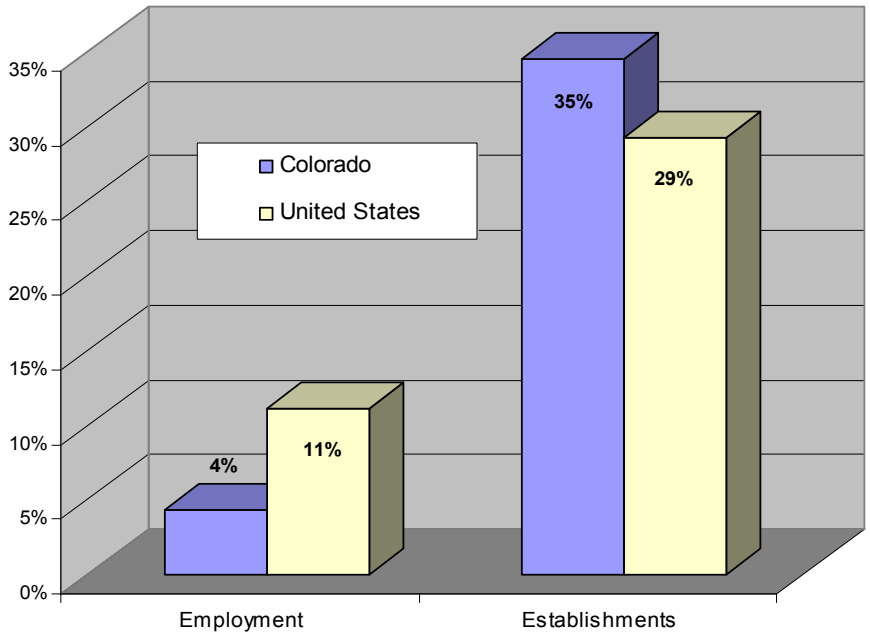
The following narrative provides an overview of Colorado's bioscience sector, as it exists in 2002, describing the general performance of the state's bioscience sector in the last four years and comparing this experience to national trends.

Overall Trends

Colorado has an established bioscience sector with a strong concentration of medical device companies and a rapidly growing research and testing subsector. While growth in the number of bioscience establishments in Colorado exceeded the national growth rate during the 1998–2002 time period, employment growth within Colorado's overall bioscience sector has not kept pace with national growth rates and the medical device sector in Colorado experienced a decline in employment during this time period. Nonetheless, components of Colorado's bioscience sector—most notably, the research and testing (biotechnology) subsector—are growing much faster than the nation and could potentially leap forward as a major driver of Colorado's technology economy. Key findings from the analysis of Colorado's bioscience sector are presented below.

Bioscience in the state of Colorado is growing in both bioscience establishments and employment, but employment increases are less than national growth. In 2002, the state had employment of 17,681 across 604 establishments in the biosciences. In the four years since 1998, employment in Colorado's bioscience sector increased by four percent. Bioscience employment for the United States increased 11 percent during the same time period. Bioscience establishments also grew in Colorado. Colorado establishments grew slightly faster than the U.S., increasing by 35 percent compared to 29 percent at the national level. Figure 3 demonstrates the respective bioscience employment and establishment increases.

Figure 3: Colorado and U.S. Bioscience Employment and Establishment Growth Rates

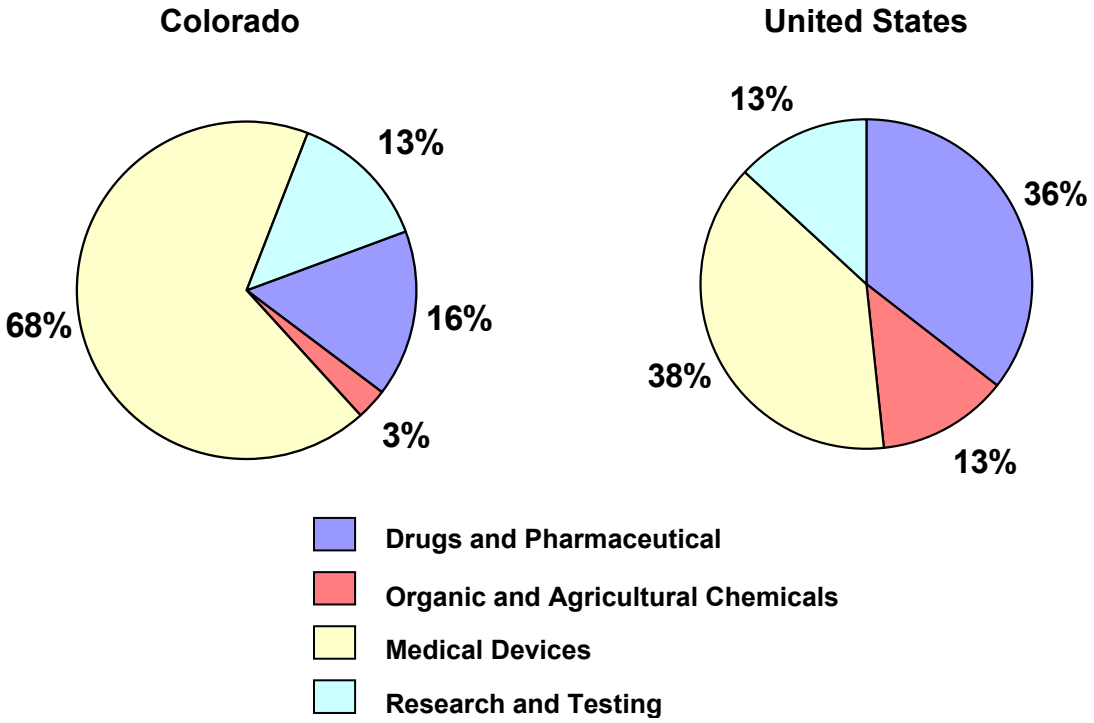


Despite employment and establishment growth, the bioscience industry in Colorado is not at a level of specialization, due to significant employment growth in the state's overall economy. When the entire private sector grows faster than an industry, it diminishes the gains demonstrated by the industry. In the years between 1998 and 2002, Colorado's total economy grew by 28 percent, growing more rapidly than the state's bioscience industry. Therefore, despite increases in bioscience employment, the industry accounts for a smaller share of total employment. The bioscience industry represents 0.76 percent of state employment. Bioscience at the national level accounts for 0.88 percent of total national employment. This gives the Colorado bioscience industry a level of employment concentration that is 87 percent of the national average. In 1998, the industry held a level of specialization equal to the national bioscience industry.

Bioscience employment in Colorado is dominated by the medical device subsector but is becoming more diversified. Examining the breakout of bioscience employment demonstrates the critical role that medical devices plays in the state's bioscience industry, accounting for 68 percent of total bioscience employment in the state (see Figure 4). In the four years since 1998, the research and testing subsector in Colorado, *a bioscience industry segment that nationally possesses many of the high-flying biotechnology firms,* increased its share of

bioscience employment. Currently the research and testing subsector account for 13 percent of all state bioscience employment, a level that reflects the subsector's performance within the national bioscience industry. The remaining two subsectors, drugs and pharmaceuticals and organic and agricultural chemicals, have gone relatively unchanged in terms of their share of bioscience employment.

Figure 4: Colorado and U.S. Bioscience Employment by Subsector



COMPONENTS OF COLORADO'S BIOSCIENCE SECTOR

National Trends

Nationally, the largest bioscience subsector is medical devices. This subsector employs just over 450,000 across 12,000 establishments. The average establishment size is 39 employees. In 2002, the medical device subsector accounted for 43 percent of establishments and 39 percent of employment in the bioscience industry.

Drugs and pharmaceuticals is the second largest subsector in terms of total employment. In 2002, the subsector employed 429,000. Similar in employment size to medical devices, the drug and pharmaceutical industry segment accounts for 36 percent of national bioscience employment. Among the bioscience subsectors, drug and pharmaceutical establishments are the largest in employment size. The average establishment employs about 72 individuals.

Organic and agricultural chemicals and bioscience research and testing are very similar in size. Each employs approximately 150,000. Together these two subsectors compose 25 percent of national bioscience employment.

Drugs and pharmaceuticals and bioscience research and testing are the fastest growing subsectors nationally. Medical devices experienced a modest employment increase, growing by two percent between 1998 and 2002. Organic and Agricultural chemicals actually declined in employment, falling by eight percent. Drugs and pharmaceuticals and bioscience research and testing demonstrated employment growth rates of 29 percent and 39 percent respectively. Establishments in these two subsectors have also increased substantially. Both observed establishments increase by 87 percent. These two subsectors are also closely related in terms of the type of the industrial activity they perform.

Often establishments that are engaged in developing new drug therapies, treatments, and methods of delivery appear in the research and testing category. Establishments in this subsector typically are in a phase of intensive research and development. Once an establishment has demonstrated a certain level of market feasibility and has begun a phase emphasizing commercialization, the establishment may be reclassified in the drug and pharmaceutical subsector.

Key Facts: Colorado Bioscience Subsectors

- Medical devices, the largest subsector, employs 11,973 and accounts for 68% of Colorado bioscience employment
- Medical devices is the most specialized subsector with a highly significant LQ of 1.52
- Employment in research and testing, the fastest growing subsector in Colorado, increased by 95% between 1998 and 2002.
- Research and testing is becoming a specialization, now accounting for 13% of the bioscience sector compared to 7% four years ago.
- Drugs and pharmaceuticals, the second largest subsector, employs 2,782 and grew by 3% in employment.
- Organic and agricultural chemicals, the smallest and least regionally specialized subsector, employs only 576.

Colorado Trends

The trends in Colorado's bioscience subsectors differ from the trends experienced nationally. The state has experienced strong growth and specializations in subsectors in which the nation exhibits relatively moderate figures. As shown in Table 3 the Colorado bioscience industry is heavily dominated by the medical device and instruments subsector. Yet, the state can potentially take advantage of emerging strengths by focusing on subsectors that demonstrate the opportunity to grow into leading industry segments.

Table 3: Colorado Bioscience Subsectors, 1998–2002

State of Colorado	Drugs & Pharmaceuticals	Organic & Agricultural Chemicals	Medical Devices	Commercial Research & Testing	Bioscience Totals	Hospitals & Laboratories
Establishments, 2002	114	51	299	140	**604**	806
Change in establishments, '98-02	36	14	43	62	**155**	166
% Establishment growth	46.2%	37.8%	16.8%	79.5%	**35%**	25.9%
Employment, 2002	2,782	576	11,973	2,350	**17,681**	59,384
Change in employment, '98-'02	84	109	-603	1,144	**734**	11,651
% Employment growth	3.1%	23.3%	-4.8%	94.9%	**4.3%**	24.4%
Employees per establishment, 1998	35	13	49	15	**38**	75
Employees per establishment, 2002	24	11	40	17	**29**	74
% Share of bioscience employment, 1998	15.9%	2.8%	74.2%	7.1%	**100%**	N/A
% Share of bioscience employment, 2002	16%	3%	68%	13%	**100%**	N/A
Employment location quotient, 1998	0.50	0.18	1.77	0.66	**1.00**	0.65
Employment location quotient, 2002	0.38	0.22	1.52	0.88	**0.87**	0.64
Change in employment LQ	-0.12	0.04	-0.24	0.22	**-0.14**	-0.01
United States						
Establishments, 2002	6,004	3,447	12,058	6,564	**28,073**	52,006
% Establishment growth, '98-'02	46.9%	14.3%	15.9%	56.0%	**29.3%**	26.1%
Employment, 2002	429,463	154,649	464,061	157,559	**1,205,732**	5,490,149
% Employment growth, '98-'02	25.1%	-8.0%	1.7%	34.1%	**11.1%**	16.1%
Employees per establishment, 1998	84.0	56	44	28	**50**	115
Employees per establishment, 2002	71.5	45	38	24	**43**	106
% Share of bioscience employment, 1998	31.6%	15.5%	42.1%	10.8%	**100%**	N/A
% Share of bioscience employment, 2002	35.6%	12.8%	38.5%	13.1%	**100%**	N/A

Data Source: Battelle Calculations from Dun & Bradstreet MarketPlace Surveys

Medical devices is the largest bioscience subsector in Colorado and the only segment that is considered to be at a level of specialization within the state. Medical devices establishments employ 11,366 people in the state. In 2002, the Colorado medical device subsector had a location quotient of 1.45, well above 1.2, which is the standard used to identify industrial specializations. This location quotient indicates that the state's medical device sector is 52 percent more concentrated than the national average. Unfortunately, the subsector experienced a five percent decline in employment since 1998. At the U.S. level, medical devices grew at a rate just below two percent. *Employment loss amidst national gains, threatens Colorado's specialization within the medical devices subsector.*

Research and testing is the fastest growing subsector in Colorado, nearly doubling in employment size since 1998. Statewide employment in the research and testing subsector is 2,350. In four years, the subsector grew at an astonishing rate of 95 percent. The 34 percent growth at the national level is also significant but well below Colorado's growth. The result is that research and testing added 1,144 jobs between 1998 and 2002. The effect of such strong employment increases has led to rising employment concentration within the subsector. The location quotient of research and testing is currently at 0.88, up from 0.83 in 1998. Research and testing is a highly dynamic, growth sector nationally with many of the typical biotech firms falling into this industry category. The state of Colorado is well positioned to capture the benefits of this key bioscience subsector.

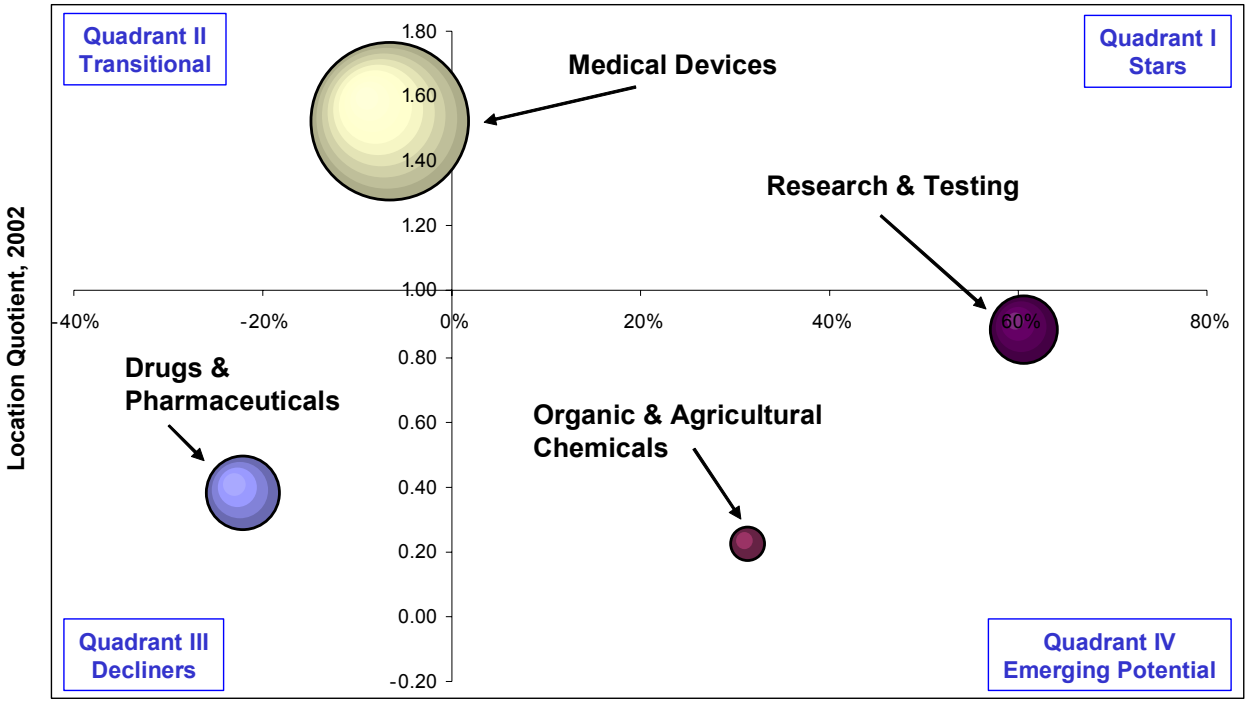
Drugs and pharmaceuticals is growing in employment, but at a rate below the national average. In 2002, the state employed 2,782 in the drug and pharmaceutical subsector. Drug and pharmaceutical establishments in Colorado average 24 workers. Nationally, the average establishment employs 72 workers. Over the past four years, Colorado's drug and pharmaceutical subsector grew by three percent. In that same period, the U.S. grew by 25 percent. Inevitably, employment growth at a rate slower than the U.S. makes it difficult for the state's drug and pharmaceutical subsector to become a specialization. Currently, the state's drug and pharmaceutical segment possesses an employment concentration that is 38 percent of the national average.

It should be noted, however, that it has been demonstrated nationally that drugs and pharmaceuticals possesses a strong link with research and testing. There is evidence to suggest that this link exists in the state of Colorado as well as there are companies that have moved from research and testing into drugs and pharmaceuticals as they have matured. Thus the growth in Colorado's research and testing subsector may serve to further strengthen the drug and pharmaceutical subsector.

Organic and agricultural chemicals has experienced employment growth, yet remains the smallest and least specialized subsector in the state of Colorado. Between the years of 1998 and 2002, employment in organic and agricultural chemicals grew by 23 percent. At the national level, the subsector actually declined in terms of employment, falling at a rate of eight percent. Even with growth well above the rate experienced at the national level, Colorado employs only 576 individuals across 51 establishments in the organic and agricultural chemical subsector. The gains in employment at the state level are exaggerated by smaller absolute number of employees in Colorado. At such a low level of employment, organic and agricultural chemicals accounts for the smallest share of bioscience activity in the state. The subsector has an employment concentration that is 22 percent of the national average.

Figure 5 illustrates the performance of the four bioscience subsectors. The graph displays the relationship between employment growth, relative to U.S. growth, and location quotient. The employment growth is found along the x-axis. The graph clearly demonstrates that research and testing and organic and agricultural chemicals have increasing employment bases. The degree of regional specialization in biosciences (location quotient) is found along the y-axis. Medical devices and research and testing illustrate the potential of solidifying their role as the primary engine in the Colorado bioscience industry. The size of each bubble signifies the subsector's employment size.

Figure 5: Colorado Bioscience Subsector Performance



Quadrant I contains subsectors that are growing and regionally specialized. Currently, Colorado does not possess any subsectors in this quadrant. However *two of Colorado's key bioscience subsectors, medical devices and research and testing, are on the verge of becoming industries that signify strong dynamic segments of the biosciences.* Quadrant II depicts industry subsectors

that are regionally specialized but not generating significant net new jobs. Subsectors within this quadrant are core strengths of the region. However, absent future growth, the specialization could become threatened. Quadrant III is comprised of subsectors with no specialization and negative comparative growth. Industries in this quadrant face considerable obstacles in becoming major bioscience drivers. Quadrant IV represents bioscience segments that are growing and emerging. These subsectors are not yet specializations but are growing faster than the nation and could potentially leap forward as a major driver of the bioscience industry.

State of Colorado Detailed Subsector Industries

It is useful to further isolate particular strengths of the subsectors. Examining industry-specific information should be approached cautiously. Interpreting the data available for four-, six-, and eight-digit SIC industries is a high level of disaggregation. At such a detailed level smaller absolute numbers exaggerate standard metrics and comparisons. In addition, the data tend not to be as consistent. In spite of these limitations, the disaggregated data can potentially reveal sources of subsector strength.

Figure 6: Key Colorado Bioscience Strengths

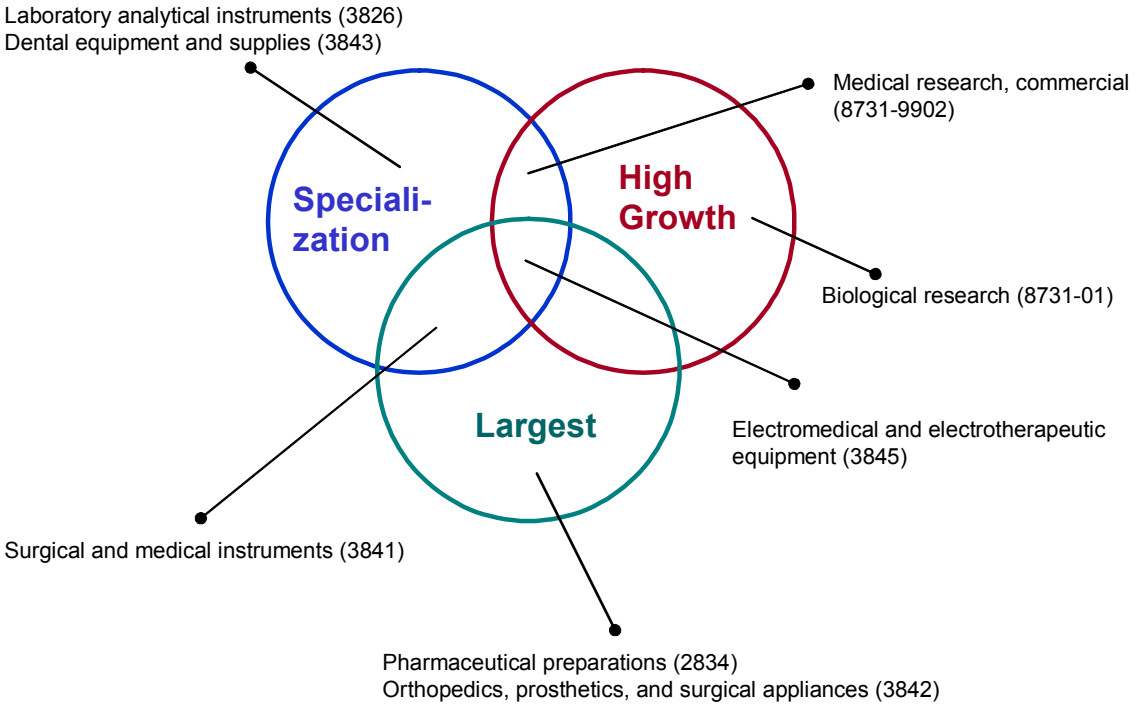


Figure 6 depicts the performance of key SIC industries in the state of Colorado. The industries were chosen based on three criteria. Industries that possessed employment concentration of 1.20 or greater were determined to be regional specializations. Industries that grew above the national growth rate were determined to be high growth. Large industries were classified based on

employment equal to or greater than 1,500. To avoid the above-mentioned data issues, only those industries with at least 450 employees were analyzed.[7]

Based on this analysis, Colorado has strengths in the following industry sectors:

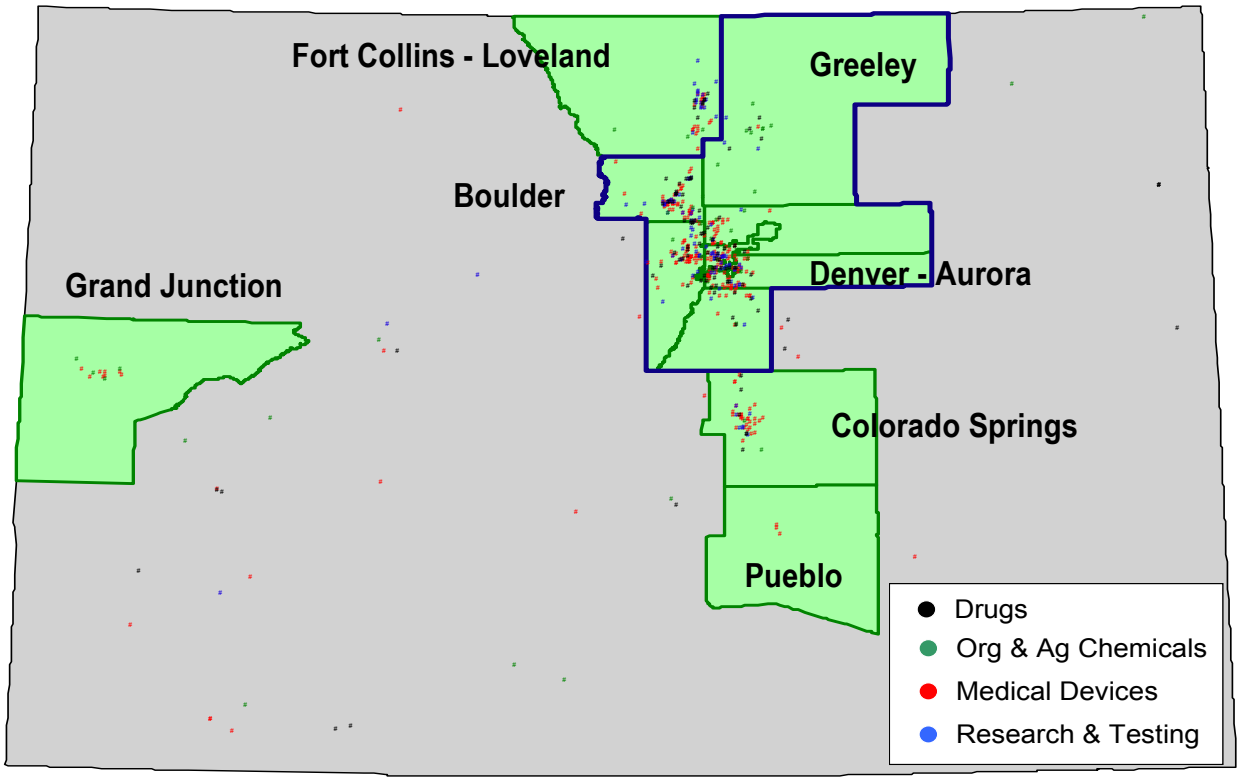
- **Electromedical and electrotherapeutic equipment**, which is a high growth industry that employs more than 1500 workers and is three times more concentrated in Colorado than in the nation.
- **Commercial medical research**, which though not yet a large employer in Colorado has experienced rapid employment growth and is a major contributor to the growth of the research and testing subsector.
- **Surgical and medical instruments,** which is the largest industry segment in the Colorado bioscience industry.
- **Biological research,** which is quickly becoming an emerging strength of the Colorado bioscience industry.
- **Dental equipment and supplies and laboratory analytical instruments**, which are specialized industry segments in Colorado.

BIOSCIENCE ESTABLISHMENTS DISTRIBUTION AND CHARACTERISTICS

The bioscience base in the state of Colorado is heavily concentrated within certain metropolitan areas. The seven metropolitan statistical areas (MSA) in the state of Colorado account for 98 percent of all bioscience employment and possess a level of employment concentration similar to the national average. Three of the seven MSAs (Boulder, Denver, and Greeley) account for 80 percent of all bioscience employment within the state. These MSAs collectively hold a level of employment concentration just above the national bioscience average. Together these MSAs have a location quotient that stands at 1.06. Figure 7 displays the location of bioscience establishments in Colorado.

[7] A detailed table of all SIC industry-specific subsectors is available in the Appendix.

Figure 7: Location of Bioscience Establishments in Colorado



SUMMARY

The bioscience sector is a growing industry in the state of Colorado, yet the industry is not at a level of specialization. Although lacking specialization at the industry level, certain bioscience subsectors possess strengths that the state can build from to spur future economic development opportunities in the bioscience cluster. Medical devices demonstrates sizable employment and a significant specialization. As the largest subsector, this bioscience segment is an important foundation for the industry in the state. Bioscience research and testing (biotechnology) is the most rapidly growing subsector. Rapid growth provides this subsector with the potential to become a new specialization within Colorado.

Colorado's Bioscience Research Strengths

One of the required platforms for creating a comprehensive bioscience development strategy is a solid understanding of the existing bioscience-related research competencies found at Colorado universities and non-profit research institutions upon which future bioscience advances may be made. Each state has its own particular core research strengths and focus areas, and, as will be shown, Colorado is no exception.

Without a strong bioscience research foundation found at universities and non-profit research institutions, it is difficult for any state or region to initiate or sustain major industry development in the biosciences. Universities and non-profit research institutions are leaders in basic bioscience research and, via academic medical centers, clinical and translational research as well. Increasingly, universities are bringing enabling technologies to the fore, helping to advance bioscience-related applications in areas such as imaging, analytical instrumentation, medical devices, diagnostics and therapeutics. Research centers are not only the key to the basic research discoveries that generate product leads for bioscience companies, but more importantly create an environment in which these bioscience companies can flourish. Moreover, research centers can be a key asset for the bioscience industry in bridging the gap between basic and applied research.

In the biosciences, there is an especially close connection between basic research discoveries and product development. This is reflected by the fact that, on average, biotechnology companies spend over 50 percent of their revenues on R&D, while the overall health care industry spends approximately 11 percent of its sales revenues on R&D. These figures exceed, by a considerable margin, the approximately four percent of total sales that R&D comprise across all industries.[8] Furthermore, across high-technology industries, studies have shown that academic research contributed most to the drug and medical product industry. One study found that 31 percent of new products and 11 percent of new processes in the biomedical field could not have been developed, without substantial delay, in the absence of academic research.[9]

Looking forward, bioscience offers enormous potential for linking basic research innovations with new market opportunities. Among the major breakthrough areas are genetic-based drug discovery approaches; integrated bioengineering solutions for major diseases that involve tissue engineering and restorative devices; advances in plant and animal sciences; and the convergence of advanced non-bioscience technologies for biomedical research, diagnosis, and treatment.

Because research is the driving force behind bioscience innovation and commercialization, it is imperative that a strategy for advancing the biosciences be built on a formal understanding of Colorado's research core competencies found at its universities and non-profit research institutions. To develop a profile of Colorado's bioscience core competencies, Battelle used the methodology described below.

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[8] R&D figures for biotechnology and healthcare industry cited from Biotechnology Industry Survey prepared by Standard & Poor's, March 2000.

[9] Edwin Mansfield, "Academic Research and Industrial Innovation," *Research Policy*, 1998, 26: 773-776.

Methodological Approach to Assessing Colorado's Core Research Competencies

There is no one single source of information that serves to identify core research focus areas at universities and non-profit research institutions. Rather, a variety of integrated and complementary analyses are required to help identify Colorado's current position and areas of focus that may lead Colorado's future bioscience growth.

In identifying core research focus areas, Battelle's objective is to identify those fields where there is a critical mass of activity ongoing, along with some measure of excellence. This does not mean that other fields of bioscience excellence may not be present at Colorado's universities and non-profit research institutions. What it does mean is that these other bioscience strengths are found in relatively limited pockets and so offer limited opportunities upon which to build.

Battelle identified core research focus areas using both quantitative and qualitative methods.

- Quantitative assessment uses statistical information on extramural grants, publications and clinical activities to develop an understanding of the trends and characteristics of bioscience research in Colorado.
- Qualitative work includes extensive field-work interviews with key administrators, scientists, researchers and clinicians across the research drivers found in the university and research institute sectors.

The questions addressed in the core competency assessment include:

- What is Colorado's overall volume of bioscience research and what trends, positive or negative, are being demonstrated?
- In which fields of bioscience and related activities is Colorado receiving significant levels of funding, especially funding from "gold standard" sources such as the NIH?
- In what bioscience and related fields do Colorado research institutions demonstrate a substantive and influential record of publication?
- What areas of bioscience and related fields do Colorado's institutions 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 in Colorado?
- Which bioscience core competencies, in Battelle's opinion, show the most promise for becoming growth poles for the Colorado Bioscience Plan?
- Which core areas of bioscience focus require additional investment in order to realize their development potential?

Through evaluation of answers to these questions, the Battelle team is able to provide insights into Colorado's university and non-profit bioscience research base and draw implications as to how these research strengths may best intersect with the region's industry base, regional competitiveness factors and market trends.

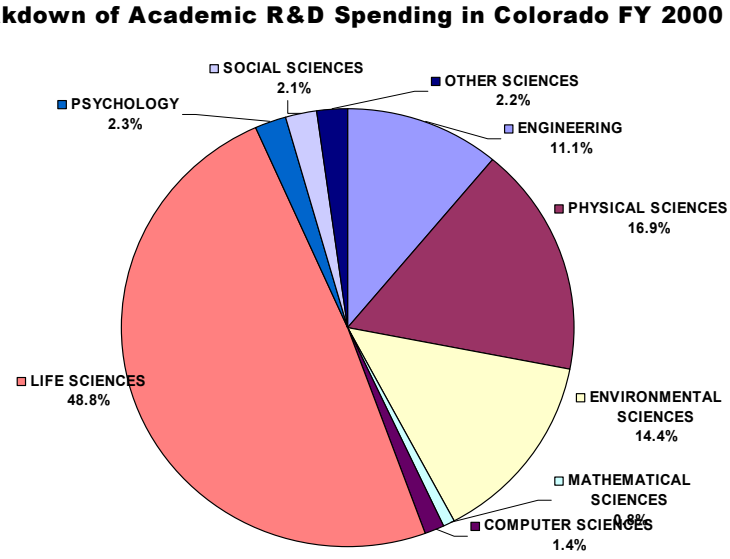
COLORADO'S BIOSCIENCE RESEARCH BASE: TRENDS AND DEVELOPMENTS

Colorado is a major source of university based scientific research—bringing substantial funding into the state—and outpacing the state's overall ranking in population. Based on research funding data compiled by the NSF, Colorado's university research base in science fields[10] totaled $559.7 million in FY 2000. This level of funding ranked Colorado 18th among the 50 states and the District of Columbia compared to its population rank of 24th in the nation.

The state's scientific position is most highly ranked by the NSF in non-bioscience fields, most notably in environmental sciences (where Colorado ranks 7th, with particularly strong showings in atmospheric and earth sciences) and in physical sciences (ranked 9th, led by a strong 3rd ranked astronomy program).

In the biosciences, Colorado is ranked 22nd in total university research funding by the NSF. Bioscience accounts for a substantial $273 million[11] in total university research in Colorado, or 48.8 percent of the university research base in the state (Figure 8). However, this falls short of the national average for bioscience as a percent of total university research, which in 2000 stood at 59 percent. A positive trend is the growth in total bioscience research funding at Colorado universities. *Total bioscience research funding reported by the NSF grew 31 percent in Colorado from FY 1996 to FY 2000, compared to 27percent for the nation*.

Figure 8: Academic R&D Spending by Field, FY 2000



In terms of NIH funding—the gold standard for biomedical research funding, which includes funding to both university and non-university entities—Colorado ranks higher (at 17th) than would be expected given its population (24th). In 2001, Colorado received $265.1 million in total NIH funding (17th in the nation) (see Figure 9).

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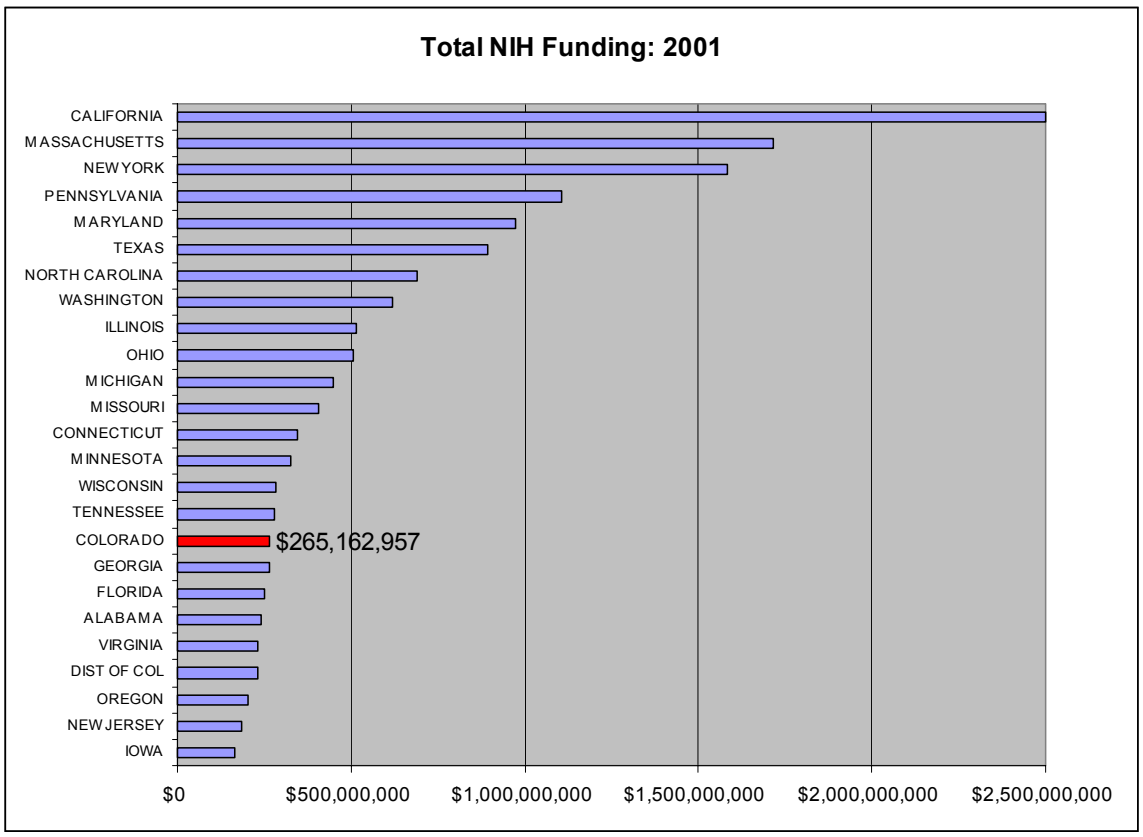
[10] Engineering, Environmental Sciences, Mathematical Sciences, Computer Sciences, Life Sciences, Psychology, Social Sciences and Other Sciences.

[11] National Science Foundation statistics for 2000

Figure 9: Total NIH Funding, FY 2001



Growth in NIH funding has experienced a more mixed performance in Colorado. Between 1997 and 2001, Colorado increased NIH funding from $200.8 million to $265.1 million, a growth of 32 percent. This rate of growth lagged national NIH funding growth, which for the same time period stood at 45 percent. In terms of 1997–2001 total dollar growth Colorado ranked 22nd, increasing its total NIH funding by $83.2 million over 1997 levels. This dollar increase exceeded the median state NIH funding increase of $61.2 million (but trailed the average increase of $122.8 million).

While statewide statistics serve to provide one perspective, it must be noted that Colorado is home to only one medical school whereas many of the states that rank higher have multiple medical schools. Colorado's medical school, at the University of Colorado Health Sciences Center performs well when compared to its individual peers. The Health Sciences Center ranks in the top quintile of all medical schools in NIH research funding (ranking 20th out of 122 total, and 8th in awards to public medical schools). With a total of $137 million in NIH funding the Health Sciences Center compares favorably to other very well known academic medical centers such as Harvard Medical

Colorado Institutions NIH Rankings

- UCHS ranks 20th out of 122 medical schools and 8th among public medical schools in NIH funding
- The University of Colorado (including all campuses) ranks 21st among universities nationally in NIH funding.
- Colorado State University ranks 12th among higher education institutions that do not have a medical school in NIH awards.
- National Jewish Medical and Research Center ranks 13th among independent hospitals in NIH funded biomedical research.

School (ranked 21st with $129 million) and Vanderbilt University School of Medicine (19th with $137.6 million in NIH funding).

It is also interesting to note that if all the NIH funds received by each of campuses of the University of Colorado[12] are summed, the total amount ($177.8 million) places the University 21st nationally in NIH funds—a strong position to hold in a country with more than 3,000 higher education institutions.

Colorado State University also performs well in attracting NIH research funds. Among higher education institutions that do not have a medical school, CSU ranks 12th in NIH funding.

Colorado's most significant private, non-profit biomedical research institution is National Jewish Medical and Research Center. In addition to the purely university based research, National Jewish makes Colorado home to the 13th ranked independent hospital for NIH funded biomedical research (with a total of $26.7 million in NIH funding).

SPECIFIC AREAS OF DEMONSTRATED STRENGTH

The previous section highlighted basic trends in bioscience activity within Colorado. In this section, Battelle extends the analysis to examine the specific areas of bioscience and bioscience-related activities that are receiving extramural funding. The volumes of funding and numbers of investigators are examined as indicators of the bioscience fields that are most active in Colorado's research institutions. NIH and NSF data are primarily used for this analysis.

In addition to examining bioscience funding levels, the Battelle research team also accessed ISI Citations data—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. ISI maintains a comprehensive database of U.S. scientific papers and associated citations, allowing Colorado's paper output to be compared to national norms and indexed for relative impact. ISI data also allows Battelle to calculate the relative concentration of individual bioscience fields within institutions against national norms.

Battelle uses the various statistical sources to derive an overview of research core competencies and to give a more specific description of the character of the biosciences in Colorado. We consider a core competency area identified when it has:

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

[12] University of Colorado Health Sciences Center, University of Colorado at Boulder, University of Colorado at Colorado Springs and the University of Colorado at Denver.

Core Competency Areas Suggested by NIH Data

Examining NIH funding more closely, at the department level, suggests specific areas of strength in Colorado. Table 4 summarizes the departments within Colorado institutions that are major recipients of NIH funding, defined as those with 15 or more NIH awards.

Table 4: Active 2002 NIH Awards

UC Health Sciences Center	Awards	UC Boulder	Awards
Medicine	174	Biology	**43**
Pediatrics	73	Psychology	**38**
Psychiatry	52	Behavioral Genetics	**36**
Pharmacology	50	Chemistry and Biochemistry	**30**
Pharmaceutical Sciences	27	Physiology	**24**
Biology	23	**Colorado State University**	**Awards**
Biochemistry and Molecular Genetics	22	Microbiology	**29**
		Biology	**18**
		Pathology	**23**

Source: NIH CRISP database and Battelle.

Moreover, Colorado has a number of leading departments as ranked by total NIH departmental funding. Colorado's university-based bioscience research is predominantly centered on the University of Colorado and Colorado State University.[13] Within these institutions, there are a number of individual departments that stand out within the NIH rankings data, as shown in Table 5.

Table 5: NIH Departmental Rankings in Colorado Institutions

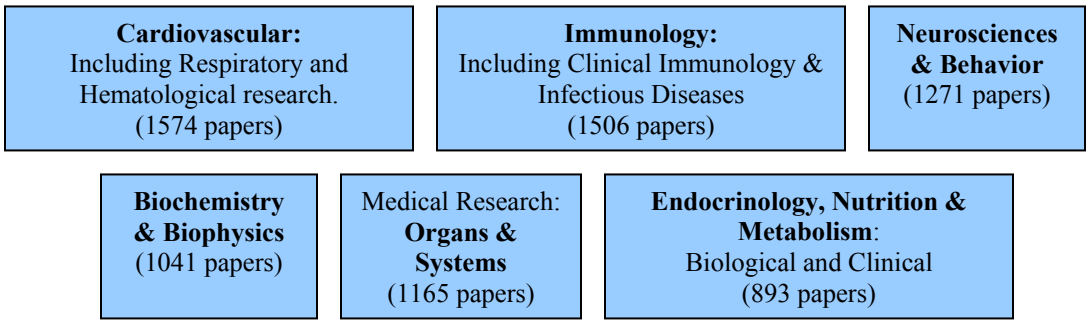
Institution	Department	NIH Rank
		Among medical schools
UC Health Sciences Center	Pediatrics	**3rd**
	Biology	**7th**
	Pharmacology	**7th**
	Pharmacy	**11th**
	Psychiatry	**12th**
	Medicine	**14th**
		Among universities
University of Colorado at Boulder	Psychology	**10th**
	Chemistry	**13th**
	Genetics	**18th**
Colorado State University	Veterinary Medicine	**3rd**

Source: NIH 2001 Extramural Awards to Medical School Departments, NIH 2001 Extramural Awards.

[13] Other institutions of higher learning, such as the Colorado School of Mines, are also engaged in bioscience research, but at significantly lower levels of research volume versus the University of Colorado and Colorado State University.

Core Competency Areas Suggested by ISI Citations Data

ISI data provide specific insight regarding the volume of publications produced by departments and the influence, in terms of citations, that the departments' work is having within their field. An analysis of the ISI data reveals that Colorado's research institutions have strong publication records across a wide variety of bioscience fields. Researchers from the University of Colorado, for example, has published more than 100 papers in each of 25 different bioscience fields between 1997 and 2001. These data show that, across the University of Colorado system, the bioscience fields with the highest levels of publication include:



Colorado State University brings publications strengths in veterinary medicine and agricultural fields. At Colorado State, the leading field of publications is veterinary medicine, which is not surprising given that it is home to the second ranked school of veterinary medicine in the U.S.[14] The veterinary school at Colorado State is a dominant bioscience player, with a publication concentration ratio more than ten times the national norm.

Related to the veterinary medicine strength and agricultural focus of the University, CSU also has a high concentration of publications in animal sciences. The field of immunology also is a Colorado State institutional strength, a field shown to also be especially strong within the University of Colorado system.

In summary, Battelle's ISI citations analysis highlights several factors relating to the biosciences in Colorado.

- There is significant institutional depth, particularly within the University of Colorado, in a broad range of bioscience, biomedical and related disciplines.
- While Colorado has clear strengths in clinical human medicine, there also exists a substantial base of expertise in basic biological sciences, animal sciences and plant/agricultural bioscience.
- Immunology as a field is strong across multiple institutions and may form the basis for key cross-cutting strengths in Colorado. This is investigated further in the core competency interviews.
- Colorado appears to have deep expertise in several additional areas, especially in biochemistry/biophysics; neurosciences/behavior; cardiovascular (and related) research;

[14] U.S. News and World Report rankings.

organs and systems; and endocrinology, nutrition and metabolism. Again, these strengths are investigated further in Battelle's field work interviews.

Areas of Colorado Bioscience Research Focus

The analysis of NIH, NSF, ISI and other published data helped set a context for understanding where Colorado's core competencies in bioscience research are focused. To further investigate these fields and deepen our understanding of the core bioscience focus areas in Colorado, the Battelle team conducted extensive interviews with administrators, faculty, and hospital and industry executives. These interviews are essential in helping develop an understanding of how the data on publications and grant awards translate into on-the-ground focus areas in Colorado.

The Battelle team's interviews were conducted with individuals who were able to identify each institution's key capabilities at a macro-level. Interviews were then conducted with department heads and individual research leaders to gain their specific insights. Along with these interviews at university, hospital and research institutions, Battelle also undertook interviews with industry executives that included a focused discussion of their research and product development activities, key technology competencies and challenges, and ongoing collaborations.

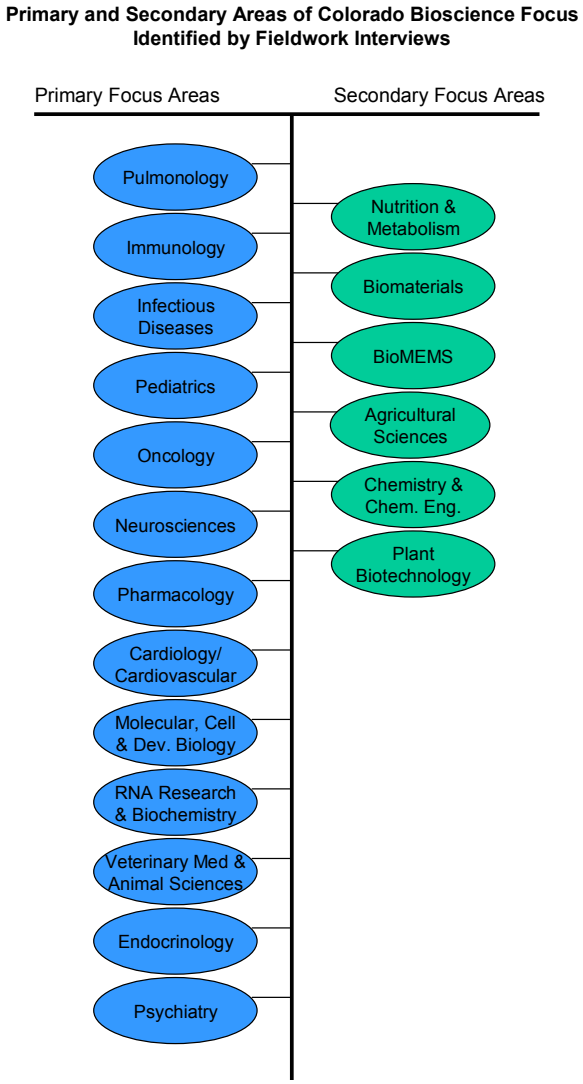
Based on the interviews and secondary data analysis, Battelle identified core focus areas in biosciences found in Colorado. Primary focus areas are those in which Colorado has two of the following:

- A significant number of well funded researchers and clinician scientists working in basic, applied or clinical research.
- Recognized clinical expertise.
- A number of commercial enterprises with R&D or production facilities working on the delivery of products or services in this field.

Secondary focus areas are more focused on one dimension or niche area, or areas in which Colorado has lower levels of research activity, clinical expertise and commercial.

Thirteen primary focus areas and six secondary focus areas were identified. These are summarized in Figure 10.

Figure 10: Primary and Secondary Colorado Bioscience Focus Areas



The characteristics of each of the primary and secondary areas of bioscience strength are discussed in the Appendix.

TECHNOLOGY PLATFORMS FOR BIOSCIENCE DEVELOPMENT IN COLORADO

The purpose for gaining an understanding of Colorado's research core competencies is to help identify the state's specific possibilities for becoming a bioscience growth pole around major niches and opportunities. Of particular importance is the ability for a state to have specific areas for near-term development within the next two to five years, which can drive not only research growth in Colorado, but also broader economic growth. It is these near-term areas for development that demonstrate that the state can be a thriving center for the biosciences and that can provide momentum for longer term investments needed to establish broader core competencies in the biosciences to sustain more diversified growth in the longer term.

Technology Platforms for Bioscience Development in Colorado

Areas with Near-term Potential
- Pharmaceutical Biotechnology
- Medical Devices and Bioengineering
- Plant Biotechnology
- Biosecurity

Areas with Long-term Potential
- Metabolics
- Computational Biology/Bioinformatics
- Biomedical Lasers and Optics

To assess near term development areas, it is helpful to consider areas of primary research focus, given the close linkages of research and industry development and the extensive reliance on research for new bioscience products. But research alone is not sufficient for ensuring bioscience development. Rather it is where research intersects with a region's industry base, competitive advantages and market opportunities that the most likely areas for bioscience development in a region can occur.

Stated more formally, the criteria for selecting near-term areas of opportunity for development include:

- The area must already be an area with existing research focus strengths.
- It should be an area that already has a base of commercial activity emerging or established within the state.
- It should be an area in which there is a distinct opportunity to leverage Colorado's comparative advantages in order to create competitive marketplace advantages.
- It should be a field in which significant product market potential exists.
- It should be a field that links to, or reinforces, other bioscience strengths and core competencies—thereby helping to enhance other fields as it expands.

Based on these criteria, Battelle recommends the following core focus areas for near term development, focus and investment in Colorado: pharmaceutical biotechnology, medical devices and bioengineering, plant biotechnology, and biosecurity. Each area is discussed briefly below. Table 6 shows the relationship between the technology platforms and Colorado's current and emerging core competencies.

Table 6: Technology Platform Linkages Across Core Competencies: Current and Emerging

Technology Platform	Basic Research	Enabling Technology	Applications
Areas Judged by Battelle to Have Near-term Growth Potential (Next five years)			
Pharmaceutical Biotechnology	Biological and Medical Sciences	Clinical Research Pharmaceutical Sciences and Pharmacology MCD Biology Microbial Pathogenesis RNA Biochemistry Structural Biology Genomics Proteomics Computational Biology Bioprocessing	Drugs/Therapeutics for Mycobacterial Diseases Neurological Drugs Cancer Drugs Diabetes Drugs AIDS Drugs Psychiatric Drugs
Medical Devices and Bioengineering	Engineering	Chemical Engineering Polymer Science Biomaterials MEMS/Nanotechnology Electrical Engineering Mechanical Engineering	Implantable materials Bioscaffolds Tissue Engineering Orthopedics Drug Delivery Intelligent Devices Diagnostic Instruments Biosensors
Plant Biotechnology	Plant and Agricultural Sciences	Plant Genomics Crop Breeding Transgenic Plants Germplasm Preservation Plant Pathogens Bioprocessing Biotech Risk Assessment Environmental Sciences	Transgenic Plants with pest/pathogen resistance Pharmaceuticals via Plant Pathways Bioprocessing of "Farmaceuticals" Environmental Monitoring
Biosecurity	Microbiology	Immunology and Infectious Diseases High Level Biocontainment Pharmaceutical Sciences and Pharmacology MCD Biology Microbial Pathogenesis Microbiology and Vector-Borne Diseases Bioprocessing Environmental Sciences	Vaccines Diagnostics Drugs and Therapeutics Environmental Monitoring

Technology Platform	Basic Research	Enabling Technology	Applications
Areas Judged by Battelle to be Opportunities for Future Development			
Metabolics	Metabolics	Clinical Research Metabolics Immunology Endocrinology Nutrition Cell Biology Cancer Biology/Carcinogenesis	Cancer Drugs Anti-Inflammatory Therapeutics Pro-Inflammatory Therapeutics Analytical Instruments
Computational Biology and Bioinformatics	Mathematics and Computer Science	Mathematics Computer Science Statistics Genomics Proteomics Biological Sciences	Basic Science Discoveries Drug Discovery and Development
Biomedical Lasers and Optics	Physics	Mechanical and Electrical Engineering Laser Physics Optical Physics MCD Biology Biochemistry and Chemical Engineering	Analytical Instruments Measuring Devices Surgery and Invasive Diagnostics Advanced Biomedical Imaging

Pharmaceutical Biotechnology

As noted above, Colorado demonstrates numerous fields in which it has bioscience depth and strength. These competencies range from considerable resources in basic biological sciences (molecular, cellular, structural and developmental biology for example) to large concentrations of expertise in specific fields of medicine (such as pulmonology, immunology, infectious diseases, oncology, pediatrics, neurology and psychiatry). These strengths suggest that Colorado has considerable opportunity to focus on pharmaceutical biotechnology applications. In the near term, a focus on therapeutics for diseases where there is acknowledged research strength within Colorado is the recommended pathway for development—leveraging existing strengths across Colorado institutions in specific inherited and acquired diseases, immunology and microbial pathogenesis. Specific Colorado strengths, as indicated by the core competency research, are listed in Table 7.

Table 7: Colorado Research Strengths that Support Development of Pharmaceutical Biotechnology

Area of Expertise	Colorado Strengths
Human Diseases	Neurological infectious diseases – an area where Colorado is claimed to have the largest cluster of researchers in the world Non-infectious neurological diseases, such as Parkinson's and Alzheimer's diseases AIDS – with the UC Health Sciences Center being recognized as one of the ten leading medical centers in AIDS research Immunological diseases
	Respiratory diseases – facilitated by the position of National Jewish as the leading center of expertise for pulmonology in the U.S., and CSU's expertise in tuberculosis research. Diabetes
	Cancer – with Colorado institutions recognized for work in multiple cancers
	Zoonotic infectious disease expertise at CSU
Animal Diseases	Viral, retroviral prion, bacterial and mycobacterial animal infectious diseases at CSU Vector-borne diseases at CSU, CDC and USDA
Plant Diseases	Plant pathogens (bacterial, fungal and insect) at CSU

In addition to the significant volume of research and clinical practice focus on specific diseases, Colorado also demonstrates depth in basic science research fields directly related to acquired and inherited diseases. Specific areas of strength include:

- ***Microbial pathogenesis*** with work taking place across institutions, examining mechanisms by which pathogens cause disease and the cellular and immune responses stimulated by pathogens. The strengths of the University of Colorado in molecular biology, molecular genetics and cell biology are of significant benefit to the understanding of microbial pathogens and associated diseases.
- ***Mycobacteria research*** a core bioscience strength at Colorado State University.
- The University of Colorado ***Molecular, Cellular and Developmental Biology*** program with work in cell biology, cell signaling, and cell differentiation among other areas.

- ***Cell and structural biology*** basic science strengths at National Jewish Medical and Research Center.
- ***Cell and molecular biology*** at Colorado State University.
- The world's leading center for ***RNA research,*** at the University of Colorado-Boulder, with basic research in RNA structure and function and applied work in RNA drugs. The University of Colorado also has an established reputation in ***protein-based drug research***.
- An emerging program in ***computational biology***, and well-resourced core facilities in ***genomics***, ***proteomics*** *and* ***advanced imaging***.

In combination with basic science and disease strengths, Colorado has "a third leg in the stool" having resources, centers and institutes in place to facilitate research programs directed at drug and biologics development. These resources include the following.

- **The University of Colorado Center for Pharmaceutical Biotechnology** is linking UC Health Sciences Center Pharmacology with the Boulder based disciplines of Pharmaceutical Sciences and Chemical Engineering. The Center is serving a coordinating role in a range of research areas and serves as a conduit for a significant number of pharmaceutical and biotech company funded projects. The Center is said to have already worked with between 30–40 biopharm companies and several companies have been spun-out.
- Development and scale-up of therapeutic compounds and biologics will be facilitated by the **Colorado Bioprocessing Center** located at Colorado State University. The Center is providing services to universities and the commercial biopharm sector in Colorado.

Examples of Colorado Pharmaceutical Biotechnology Companies

- **Amgen** – one of the leading biotechnology companies that develops and markets naturally occurring proteins, antibodies and small molecules
- **Atrix Labs** – a drug delivery and drug development company
- **Array Biopharma** – drug discovery company investing small molecule drugs through the integration of chemistry, biology, and informatics
- **Heska Corporation** – developing vaccines and medical products for dogs, cats and horses.
- **Myogen** – a biopharmaceutical company focused on discovery development and commercialization of therapeutic drugs for the treatment of cardiovascular diseases
- **NaPro Bio Therapeutics Inc**., focused on the development, production and licensing of novel genetic technology for applications in agribiotechnology, pharmacogenomics, and human therapeutic and diagnostic applications
- **PR Pharmaceuticals** – working in sustained release technologies for injectable, oral and transmucosal drugs
- **Replidyne** – focused on identifying and developing antimicrobial drugs to treat infectious diseases
- **Ribozyme Pharamaceuticals (RPI)** – developing novel RNA based therapeutics, diagnostics and drug manufacturing platforms
- **Summit Plan Laboratories** – focused on micropropagation, applying cloning and greenhouse technologies to produce planting stocks.

Colorado also has a base of companies involved in drug development and drug delivery systems. See text box.

If pharmaceutical biotechnology in Colorado is to be expanded and fully exploited, core focus areas need to be established. It would appear, based on the proceedings of the Butcher Forum that there is a definite desire at the University of Colorado to identify a field or fields of focus for

bioscience development. Battelle perceives that many of the elements required to form a successful biopharm engine are in place in Colorado. The logical focus for Colorado's major research institutions is the pursuit of discoveries and commercializable biological products. What is required is agreement on initial areas of focus and a structure to facilitate the process.

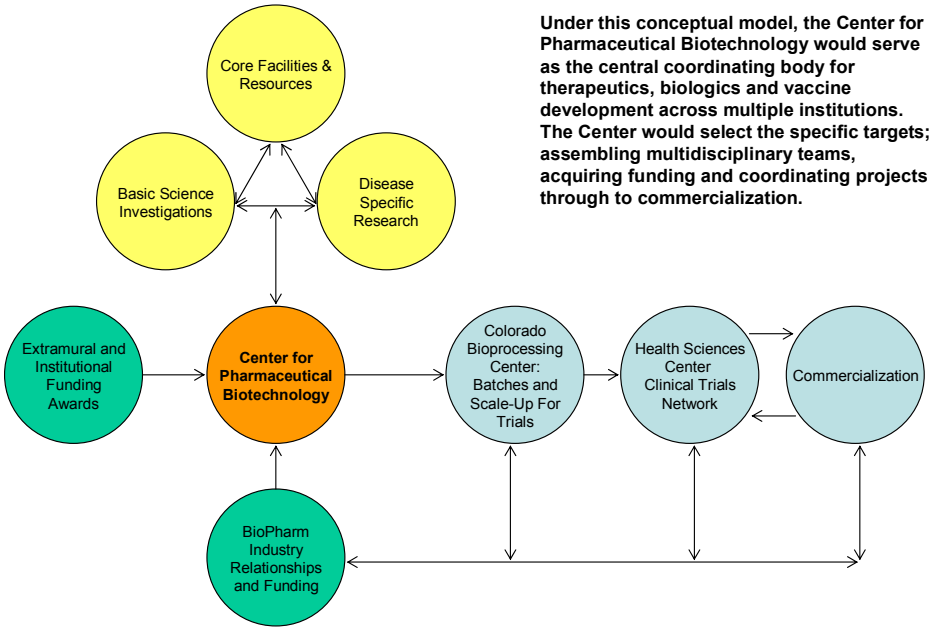
Based on the areas of expertise identified in the core competency work, logical initial biopharm R&D focus areas for Colorado could be selected from the following:

- **Drugs for neurological disorders** – building on broad spectrum of neuroscience expertise at multiple campuses and the acknowledged capabilities in neurological diseases contained at the Health Sciences Center. There is a wide market for therapeutics related to Alzheimer's disease, Parkinson's disease and Multiple Sclerosis, plus emerging concerns surrounding effective diagnosis and treatment of prion-based neurological diseases (which would leverage expertise at the CSU School of Veterinary Medicine and protein expertise at UC-Boulder).
- **Drugs and therapeutics for mycobacterial diseases**. Mycobacteria are the cause of tuberculosis and leprosy, and a leading cause of opportunistic infectious diseases in persons with compromised immune systems (such as persons with AIDS, CGD, SCID, etc.). A Colorado-based focus on Mycobacterial diseases would leverage existing work with the bacteria at National Jewish Medical and Research Center (TB expertise) and at the CSU Microbiology Department's Mycobacteria Research Laboratory. It would also directly link to the University of Colorado's strengths in the MCD biology program, microbial pathogenesis, immunology, infectious diseases and AIDS work. Cost effective solutions to Mycobacterial diseases would have a huge impact on world health,[15] and would provide a suitable mission focus for the Center for Enhanced Global Health concept proposed at the Butcher Forum and Symposium.
- **Cancer or diabetes drugs and therapeutics** would be two other potential targets. In both disease areas Colorado has deep institutional strengths.

Whichever focus is ultimately selected a center model should be adopted to coordinate funding and cross-institutional, multi-departmental collaboration. One logical approach would be to build upon the existing Center for Pharmaceutical Biotechnology that bridges the Boulder and Health Sciences Center campuses, extending it to enhanced interaction with Colorado State University and other state bioscience research establishments. A conceptual model for integrating resources is shown in Figure 11.

[15] According to statistics published by the University of Cape Town Division of Medical Microbiology, Tuberculosis is responsible for 25 percent of adult deaths in the developing world, with between 8–12 million new infections per year and between 2–3 million deaths (more than those caused by diarrhea, malaria and AIDS combined). There are approximately one million worldwide active cases of Leprosy.

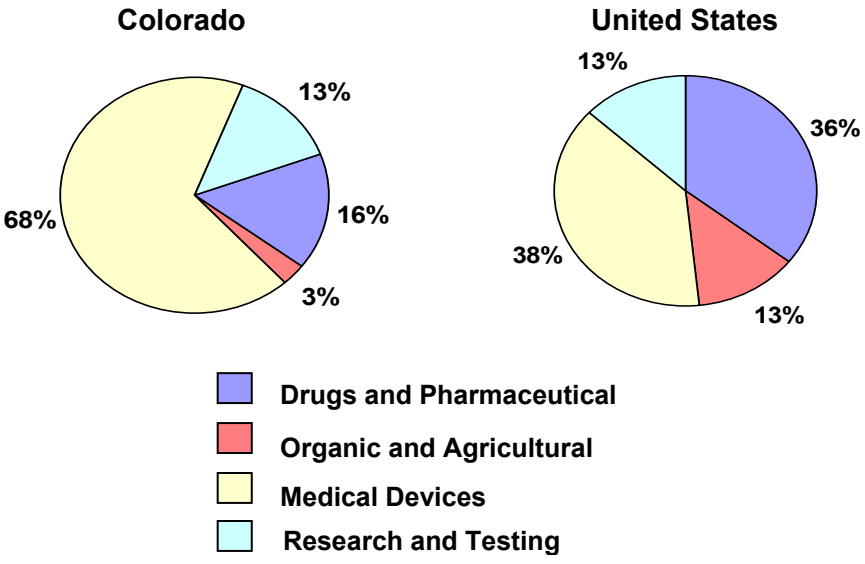
Figure 11: Conceptual Model for Integrating Resources



Medical Devices and Bioengineering

Colorado does not currently show a macro-economic industry specialization in most areas of the biosciences—the one area where it does have commercial bioscience specialization is in medical devices and instruments as illustrated in Figure 12.

Figure 12: Medical Devices and Bioengineering



Some examples of Colorado-based medical device and instrumentation companies are listed in the text box.

Examples of Colorado Medical Device and Instrument Companies

- **Baxa** – developer of oral liquid delivery systems and IV drug admixture and delivery.
- **Cobe Cardiovascular** – a leader in open heart surgery technology.
- **Cytomation** – applying electronics and computing technology to improve flow cytometry.
- **Datex-Ohmeda** – a division of Instrumentarium Corp., one of the world's leading medical technology companies that develops, manufactures and markets products for anesthesia and critical care.
- **Gene Check** – producing and markets reagents and kits for research and veterinary applications.
- **Gambro** – develops and markets automated blood collection and information systems
- **Sandhill Scientifican** – industry leader in gastrointestinal diagnostic.

Within the academic research sector, the core competency research identified biomaterials and bioMEMS/nano-technology as potential focus areas. Special areas of focus include:

- **Application of photopolymerization to the production of novel biomaterials**. Photopolymers are demonstrating numerous characteristics that may lead to their success in biomaterial applications. In particular, these materials are demonstrating controllable degradation characteristics. Researchers at the University of Colorado in Chemical Engineering are applying photopolymers to applications in tissue engineering scaffolds, complex in-situ 3D structures, dental implants, and the production of micro and nano photopolymer particles for the delivery of drugs and DNA. The work is directly drawing on the University's strengths in polymer chemistry, physics and biophysics and molecular and cellular biology.
- **Development of intelligent biomedical devices and musculoskeletal systems** through a multi-institutional center directed out of the Colorado School of Mines Engineering Division. The Center was established via NSF funding in 1998 and has become a leading center for the development of bionic orthopedics, human sensory augmentation, exoskeletons and smart orthoses. The School of Mines also hosts the Colorado Institute for Macromolecular Science and Engineering which has 14 faculty members predominantly looking at polymers and biofluids.
- Within electrical and computer engineering at the University of Colorado bioengineering work is focused on **bioelectronic magnets and ultrasonic fields for the development of diagnostic and therapeutic instruments**. Scientists and engineers are also working in neurobiological engineering and producing biomedical instrumentation devices for therapeutic testing in the space program. The group's expertise is also being leveraged in projects in optical biosensors and laser surgical probes.
- Within the Department of Mechanical Engineering at the University of Colorado a core biomedical focus is in **MEMS devices for cardio-vascular applications**. Mechanical Engineering also contains several faculty members working on reliability and structural characteristics of various biomaterials.
- At Colorado State University biomaterials work is focused within Chemistry and within Chemical Engineering where there is work on **biosensors** and also work in **biomaterials design focused on polymer surface interactions with cells and bacteria**.

Also of note is the Colorado Alliance for Bioengineering (CAB). The Colorado School of Mines, UC-HSC, UC-Boulder, UC-Denver, the University of Denver and Colorado State University have created a consortium to advance bioengineering and research in Colorado. CAB serves as a clearinghouse for the bioengineering research community and has developed an online searchable database of faculty researchers in bioengineering.

As with other areas of bioscience in Colorado, bioengineering is quite diverse and diffused across multiple campuses. It does appear, however, that an opportunity exists in the near term to convene a formal product development lab that would provide support services for moving concepts from the lab bench into applied-commercial research. Such a product development lab would be the natural place for Colorado's academic bioengineering community to interact with industry researchers and research sponsors.

Plant Biotechnology

The genomic and biotech revolution is paving the way for the creation of significantly altered plant, and animal, life forms. Gene transfer can now be achieved across totally unrelated species and previously impenetrable biological boundaries. Before the genomic revolution, the development of disease, pest and agricultural chemical resistant crops had to occur through traditional plant breeding techniques. Post-revolution, positive genetic traits of one species can be transferred to the DNA of completely unrelated species—allowing, for example, "antifreeze" protein genes from flounders to be transferred to a tomato to engender enhanced frost resistance. This one example serves to show the almost infinite possibilities for novel plant strain development that may result from gene transfers.

Tremendous benefits may result[16] from the application of genomics to plant biotechnology, some examples being:

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

Battelle's research indicates that the Colorado bioscience environment is well positioned to assume leadership within the fast moving field of plant biotechnology. Some of the existing Colorado plant bioscience assets include:

- Colorado State University is home to the national Center for Genetic Resource Preservation and, therefore, holds a huge repository of plant germplasm. The germplasm storage at the Storage Laboratory represents a potentially substantial local resource for research.

[16] Like many new technologies, plant biotechnology also carries risks. The large scale potential for generating new species could result in considerable health and environmental risks if control over these species is lost and they enter the planets general ecology.

- Colorado State University's Department of Bioagricultural Sciences and Pest Management has a focus in agricultural biotechnology and works to apply molecular biology and genetics to crops, weeds and plant pathogens. Colorado State University has recognized programs in crop breeding using both traditional and genomics-based approaches and has a focus on genomics in work relating to pesticide resistance and natural pest resistance. The institution also has emerging strengths in plant molecular biology. The Colorado Bioprocessing Center has expertise in biotechnology production processes and fermentation, skills that may be applied across into the processing of pharmaceuticals and other biotechnology products produced through plant genetic pathways.
- The University of Colorado – Boulder brings strengths in plant physiology that can be applied to improving nutritional benefits from plants, while the broader base of the University of Colorado's expertise in pharmaceutical sciences, pharmacology, molecular biology, DNA/RNA and protein technologies can each be applied to progressing work in plant biotechnology and "farmaceuticals."[17]

Bolstering support for a Colorado focus on plant biotechnology is a work released at a recent Economic Development Council of Colorado forum held on ag-biotech and transgenic pharmaceuticals as an emerging target industry for the state. Papers and proposals discussed at this forum highlighted multiple attributes of Colorado's Front Range environment that would be conducive to transgenic crop production.

There is a potential link, of course, between a Colorado focus on plant biotechnology/transgenic pharmaceuticals and the recommended focus on Pharmaceutical Biotechnology outlined earlier in this report. The long-term potential exists for Colorado assuming a leadership position in both the discovery, testing and development of drugs and therapeutics for specific diseases and the growth of the state in the development of novel and efficient pathways for therapeutics production through plant biotechnology.

Risk Assessment and Monitoring as an Additional Plant Biotechnology Focus

Interviewees also noted that Colorado State University has expertise in transgenic crop and biotechnology risk assessment. While tremendous benefits are anticipated from the application of genomics to plant biotechnology as discussed above, the movement of genes from one species to another also has the potential to generate significant environmental and ecological problems. The University of Colorado, Colorado State University and the Colorado School of Mines are known for their environmental, earth science, ecology and atmospheric science programs and, therefore, a potential exists for the state to operate leading bioscience programs in biotechnology and transgenic risk evaluation and mitigation. Opportunities would exist for the development of monitoring devices and instrumentation, surveillance systems, diagnostic tests, computer simulation and modeling software, and environmental impact consulting services for example. The following potential risks of biotechnology serve to illustrate the potential scope of the risk assessment, monitoring and mitigation science that will be required:

- Cross-contamination of genes has the potential to create herbicide resistant weeds or contaminate normal food crops with medicinal genes.

[17] "Farmaceutical" is a name that is starting to be applied to the production of pharmaceuticals through farming practices. The term Pharming is also being used to describe this area of scientific inquiry.

- Residue from the harvesting of transgenic crops could wash into ground water and streams.
- Seed eating birds, insects, and foraging animals will be exposed to drugs and enzymes contained in transgenic plants.
- Environmental contact between drug-bearing plants and bacteria or insects could, over the long-term, result in resistant forms of "super-bugs" as has happened through the use of antibiotics in traditional medicine.
- Pesticide resistant crops may "escape" into the environment causing problems similar to those encountered when exotic plants or animals are introduced into an environment in which they have no predators.
- The prospect that new recombinant viruses could be formed via virus resistant transgenic crops interacting with naturally occurring environmental viruses.

Colorado is, therefore, presented with two plant biotechnology paths that it can follow at the same time. Both have commercial product potential and would leverage the skills and proven expertise of existing Colorado scientific and research institutions.

Biosecurity

The federal government is taking the threat of bioterrorism extremely seriously. The events of September 11, 2001served to awaken the nation to the extreme cunning and viciousness of international terrorists. The World Trade Center attack leaves no doubt that al-Queda would have no hesitation in using any weapon of mass destruction (WMD) that fell into their hands—indeed the CIA warns that the al-Queda network has made obtaining WMD capability a very high priority.[18]

The threat comes from multiple potential weapons, including nuclear bombs, radiologic bombs, chemicals and biological weapons. The threat is also to multiple potential targets including humans, livestock and agricultural resources. While the threat of a nuclear bomb or chemical weapon must be taken seriously, many terrorism experts note the technical difficulties involved in acquiring, developing, transporting and detonating/dispersing such weapons[19]—whereas an individual with smallpox in the contagious phase can deliver a "bio-weapon" simply by visiting crowded areas.

Bioterrorism thus presents a very real danger for the United States and the federal government is acting swiftly to fund programs that may act to counter the threat. The threat is posed by multiple potential diseases and biological agents including: anthrax, botulism, plague, smallpox, tularemia, and viral hemorrhagic fevers (Ebola, Yellow Fever, Rift Valley Fever, etc.)

Compounding the threat of these known disease agents is the potential that genetic engineering technologies could be used to:

- Enhance/expand the transmission (infection) characteristics of the infectious agent
- Increase an infectious agent's resistance to known antidotes or antibiotics

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[18] Bowman, Steve. "Weapons of Mass Destruction: The Terrorist Threat." Congressional Research Service Report for Congress. March 7, 2002.
[19] Bowden, Ibid.

- Bioengineer new infectious agents through recombinant DNA technology.

As noted above, humans do not have to be the target for terrorists to cause "terror" and substantial economic and social disruption. Hence there is also a concern that food sources, be they livestock or crops, could be targeted. The UK outbreak of foot and mouth disease caused tremendous economic and social damage—a similar outbreak in the U.S. ranching community could be devastating. More distant as a threat, but still a potential, is the fact that if genes can be introduced to food crops to produce pharmaceuticals so could genes be introduced to produce toxins.

Because of the breadth of bioweapon threats, the federal government is funding multiple counter terrorism initiatives. The National Institute of Allergy and Infectious Diseases (NIAID) is funding four regional centers of excellence in bioterrorism and emerging infectious diseases and Colorado State University (in collaboration with the UC Health Sciences Center and the Centers for Disease Control lab at the CSU Foothills Campus[20]) have a reasonable expectation that they may be one of these centers. Whether successful or not in this center application, Colorado has much to contribute and leverage in developing a counter-bioterrorism research and commercial sector.

Colorado's Rocky Mountain Institute for Biosecurity Research leverages CSU's expertise and extensive statewide Cooperative Extension and Agricultural Experiment Station are being used to address biosecurity issues such as chemical, biological and radiological threats. The Institute integrates university research expertise in infectious diseases, plant and animal biological agents and atmospheric science under one umbrella organization to plan and coordinate projects to meet national and state needs. The Institute is engaging statewide networks to monitor and assess possible threats and disseminate education and information to the general public. It also partners with federal researchers located on or near the CSU campus and other land-grant universities within the Rocky Mountain region.

In addition, Colorado's existing assets include:

- Colorado State University's expertise in human, animal and plant infectious diseases, with a special concentration on vector borne diseases. Indeed, CSU and the CDC are creating a consortium to leverage the skills in this area in collaboration with Utah State University and the U.S. Department of Agriculture Vector Borne Diseases Lab in Wyoming.
- The Fort Collins based Centers for Disease Control (CDC) laboratory at the CSU Foothills Campus. The CDC's director of bioterrorism preparedness has been quoted as saying that the Foothills Campus "lab's budget and staff are expected to balloon as its responsibilities expand."[21] The CDC's maintains a list of emerging infectious diseases that includes dengue, yellow fever, West Nile virus and bioterror diseases such as plague, tularemia and equine encephalitis. The CDC lab in Fort Collins tracks them all and serves to coordinate the nation's public health response in the case of outbreaks. The CDC lab maintains six BSL-3 laboratories.

[20] A GMP production facility is part of the proposal assembled by the consortium.
[21] Erickson, Jim. "Tiny bugs, big trouble: dangers from insects, terrorists spur drive for an expanded CDC lab." Rocky Mountain News. August 26, 2002.

- The University of Colorado – Boulder's growing efforts in microbial basis for human diseases, building on more fundamental research from RNA analysis involving developing techniques to identify microbes without cell cultures.
- The University of Colorado's expertise in pharmaceutical sciences, pharmacology, molecular biology, DNA/RNA and protein technologies.
- Plus, the U.S. Department of Agriculture (USDA) vector borne diseases lab in Laramie, Wyoming which, in combination with the CDC and CSU labs, comprises the single largest concentration of vector borne disease expertise in North America.
- CSU is uniquely positioned as the State's land grant university to expand the collaborative research funded by the USDA, Cooperative State Research Education and Extension Service (CREES), Animal Plant Health Inspection Service (ARS) and U.S. Forest Service, and the Natural Resource Conservation Service. USDA-funded basic and applied research expenditures totaled $16.5 million in fiscal year 2002 and is CSU's second largest external sponsor.

The scale of the biosecurity opportunity in terms of products and services is hard to overstate. There is a potential need to monitor every agricultural food product, every livestock animal and all human environments. All could be the subject of an attack and each may present a market for monitoring and surveillance devices, diagnostic tools, vaccines, antidotes, therapeutics, etc. Indeed, there is a logical link to the types of opportunities for risk assessment and mitigation highlighted for transgenic crops previously in this report. There are also links to the previously recommended center for Pharmaceutical Biotechnology.

Longer Term Bioscience Potentials for Colorado

During our research interviews the Battelle team identified a number of technology platforms that represent longer term bioscience sector development potentials. The identified areas mainly consist of relatively compact groups of people working in leading edge fields, or new formative centers just recently pulled together. In Battelle's opinion, the longer-term potential focus areas in Colorado include:

- **Metabolics** – Battelle's research identified several groups working in and around the field of Metabolics within Colorado. This includes, for example, the new Metabolics Institute recently approved by the Board of Regents for the Colorado Springs Campus of the University of Colorado. The Institute will focus on the relationship between metabolism and the immune system, examining the effect on life/death decisions of cells. This focus is thought to be directly relevant to a pathway that could generate cancer, anti-inflammatory and pro-inflammatory therapeutics. Additional work is taking place at the University of Colorado in metabolic instrumentation and monitoring.
- **Computational Biology/Bioinformatics** – The field of Computational Biology (also encompassing Bioinformatics) is still in its formative stages within the state. The University of Colorado has the Center for Computational Biology, but this is still a comparatively new center and does not have a physical home or a reliable line of funding. Despite impediments the center now has between 55–60 faculty associated with it, and has launched certificate, masters and PhD programs in computational biology, bioinformatics and computer science. For Colorado to be able to fully leverage the opportunities highlighted in core technology

platforms discussed earlier, enhanced capabilities in Computational Biology need to be fostered. The Center for Computational Biology should receive baseline funding to allow it to grow its programs, plus it will need to be allocated space at the Fitzsimons research campus since Computational Biology will be a core resource for work in many bioscience focus areas. This is a possible area of broader economic development opportunity in Colorado given the strong base of information technology industry found in the state.

- **Biomedical Lasers and Optics** – The National Institute of Science and Technology (NIST) funded JILA operation at the University of Colorado, an interdisciplinary institute for research and graduate education in the physical sciences, contains some of the worlds leading experts in lasers, laser physics and advanced optics. Currently the JILA team is working only to a limited degree in applying their expertise to biomedical laser and optics applications—however, the depth of science and technology know-how within JILA and associated University of Colorado departments could lead to significant work in biomedical instrumentation and measurement tools, micro-surgical devices and imaging applications. Currently the main biomedical related activities include work with "optical tweezers," a type of focused laser beam, with the goal of developing assays and precision instruments for measuring the properties of single-DNA-based molecular motors.

SUMMARY

The biosciences have been identified as the underlying technology platform for the growth of state and regional economies in the coming decades. States such as Michigan, Pennsylvania and Wisconsin have recognized the opportunity to leverage their academic and non-profit bioscience research institutions to form growth poles of innovation in this dramatically advancing field.

Colorado has a legitimate opportunity to emerge as a leader in many areas of bioscience and biomedical development. There is significant, world-class work taking place in the biosciences and related fields within Colorado—and the core competencies and technology platforms identified by Battelle show considerable potential for growth in research volume, research impact and commercializable innovation.

The key to realizing Colorado's true bioscience potential is the extension of the institutions "without walls" already been recognized by the University of Colorado in its institution "without walls" concept. Colorado has a breadth of expertise across many bioscience fields—fields that can be brought together in collaborative initiatives to spark creativity and new discovery. This report includes recommendations for what these areas of collaborative science may be. Colorado's institutions must now organize and structure for collaborative delivery on these technology platform potentials.

Competitive Assessment of Colorado's Bioscience Infrastructure

The San Francisco Bay Area, Boston, the Baltimore/Washington DC region, the New York and New Jersey metro area, and San Diego are generally regarded as the nation's premier bioscience centers. An examination of the factors that have enabled these regions to succeed in growing their bioscience bases shows that they share a number of characteristics. The Bay Area's assets, for example, include its superlative research institutions, a strong quality of life (albeit at high cost), an unmatched pool of venture capital including firms skilled in early-stage start-ups, agile small firms willing to work in partnership on an ad hoc basis, and a highly skilled and mobile workforce. Boston's success can be attributed to the presence of MIT and Harvard and the clinical network of Harvard affiliated hospitals. Boston has also built on the region's engineering strength to develop a significant concentration in medical devices. The key factors that have led to these regions' success are discussed below.

Key Success Factors

- Engaged research institutions with active leadership
- Intensive networking across sectors and with industry
- Available capital covering all stages of the business cycle
- Discretionary federal or other R&D funding support
- Workforce and talent pool on which to build and sustain efforts
- Access to facilities and equipment
- Stable and supportive business, tax, and regulatory policies
- Patience and a long-term perspective

KEY SUCCESS FACTORS

Engaged Research Institutions

Many regions have important or even outstanding R&D assets in the biosciences, particularly around their higher education institutions and medical centers or teaching hospitals. Without major research stature, reputation, and standing within given fields, no region can succeed with a bioscience-driven strategy for its economic growth. An outstanding research university is required to become serious about the biosciences. But it takes more than simply research stature. It requires the capability to engage industry, directly or indirectly, to convert this intellectual knowledge into economic activity. To do so requires one or more of a region's research universities committed to engaging with and helping to build and sustain a bioscience community locally. At least one institution needs to be willing to play the role of Stanford and Berkeley in the San Francisco Bay Area, MIT in Boston, UCSD in San Diego, or the three universities of Research Triangle Park. To succeed, a region must have a university that has already made this commitment or a state government committed to using discretionary R&D funding to induce its public and private research universities to undertake that commitment.

Intensive Networking

As many observers of high-tech clusters have noted, the most successful clusters facilitate extensive and intensive networking among technology companies and their managers and employees. In a very few leading communities like Silicon Valley, this networking has occurred

naturally, with formal organizations like Joint Venture-Silicon Valley coming only later. However, in the vast majority of American regions, such organizations need to be *built* from the ground up, because otherwise the desired degree of networking will not occur. These technology intermediary organizations—whether they are regional or state biotech organizations, regional or state technology councils, or some other combination—perform several interrelated and important functions.

- Providing neutral organizational ground where the very different cultures of academia, industry, and government can meet over a common regional growth agenda.
- Providing a point of contact where sectoral trade associations can come together to promote a common agenda.
- Spurring the formation of joint ventures or virtual-company formation in sectors with large numbers of smaller players.
- Leading special interest groups of people with similar job functions (CEO, CFO, CIO, etc.) in various technology businesses across many sectors.
- Building tighter supply chains, reducing the time to market for innovative firms by connecting them with vendors of products and services.
- Giving technical, professional, and managerial employees a sense that there are other options to turn to if a given venture fails.

Available Risk Capital

One characteristic shared by leading bioscience regions is that they are home to a venture capital community that is both oriented toward early-stage investment and committed to local investment. It is critical to have local venture capital funds with experience investing in bioscience companies. These regions also have networks of successful bioscience entrepreneurs who act as angel investors, willing to invest in very early stage start-up companies. Building a base of angel investors and venture capital funds able and willing to invest in bioscience companies is a challenge for regions with emerging bioscience sectors.

It is also critical to have financing available for each stage of development from early-stage, proof-of-concept and prototype development to venture financing. Leading bioscience regions have access to the following types of capital:

- ***Commercialization funding,*** which can be used to assess and undertake a review of the commercial potential of completed R&D. This assessment must be done before a business can be spun off, and may include prototype development, reduction-to-practice exploration, and other steps.
- ***Pre-seed and seed funding*****,** i.e., financing to support very early stage start-up companies.
- ***Venture financing***, which is the capital needed prior to initial public offering. Given the long time frame required for the regulatory review process that must be completed before bio-science companies can introduce products in the marketplace, bioscience firms will often require multiple rounds of venture financing.

Discretionary Funding

To build generic R&D assets into an effective attractor of technology investment requires leverage of substantial, ongoing, external, discretionary funding. While technology leaders like Silicon Valley, Route 128 in the Boston area, and San Diego were able to leverage decades of heavy defense contracting, and while Baltimore/Washington leveraged growing congressional support of federal laboratories owned by NIH, NIST, and the FDA, most regions must use state funding as a lever for acquiring strategic external investments from:

- **Merit-oriented federal science agencies**, focusing on proposals that require non-federal investment in facilities or instrumentation in order to be competitive
- **Line-item appropriations (earmarks)** for facilities or science programs, and particularly those that require good-faith local matching
- **Local corporations** willing to invest part of their R&D portfolio in the region if they can leverage their support with other funding
- **Local foundations** that are increasingly seeing technology-based economic development as consistent with their goals for economic opportunity.

Workforce and Talent Pool

Like any knowledge-based industry, bioscience companies need a supply of qualified, trained workers. To meet the demands of newly emerging fields, new curricula and programs need to be developed by educational institutions working in close partnership with the bioscience industry. In addition to having world-class researchers, successful bioscience regions have an adequate supply of management, sales, marketing, and regulatory personnel experienced in the biosciences. Regions such as San Francisco, San Diego, and Maryland have established bioscience workforce initiatives across a range of the educational spectrum. The initiatives include the following.

- Establishing biotechnology technician two-year associate's degree programs.
- Offering new master and doctoral level programs in the bioscience field.
- Determining skill training and education needs through regular and continuing outreach to bioscience companies.
- Using new delivery approaches to reach students.

Access to Specialized Facilities and Equipment

Facility costs are among the most significant expenses of a new bioscience firm. These firms need access to wet lab space and specialized equipment. Since most bioscience firms initially lease space rather than purchase it, an available supply of facilities offering space for bioscience companies is critical. Ensuring that the private marketplace offers the right amount and type of space suitable for the development and growth of bioscience firms can be a major challenge. Regions have sought to meet this need by developing incubator facilities and helping firms to finance facilities and leasehold improvements. To provide firms with access to specialized equipment, states and regions have invested in research centers and shared-use facilities, such as bioprocessing scale-up facilities.

Supportive Business, Tax, and Regulatory Policies

Bioscience companies need a regulatory climate and environment that encourage and support the growth and development of their industry. Tax policies that recognize the long development cycle required to bring new bioscience discoveries to the market can provide additional capital for emerging companies as well as ensure an even playing field in state and local tax policies between older, traditional industries and emerging industries such as biosciences.

Patience and a Long-Term Perspective

One final lesson from every successful technology community is that success takes time. Silicon Valley and Route 128 trace their origins in electronics to the 1950s, and in life sciences to the 1970s. Research Triangle Park represents a 50-year strategy that has only recently found its footing in the biosciences and is still working to develop full capability in the entrepreneurial sector.

Table 8 compares Colorado on each of these lessons with best practice bioscience states and regions on the key success factors.

Table 8: Comparison of Colorado to Best Practice Bioscience Regions

Factors of Success	Best Practice States/Regions	Colorado Situation
Engaged Universities with Active Leadership	✓ Universities are engaged in economic development and committed to technology transfer. ✓ Have created vehicles for technology commercialization.	✓ Higher education and bioscience industry have a weak record of collaboration. ✓ Improvements have been made in technology transfer and commercial-ization, but time is needed for technology transfer improvements to mature and greater investment in technology commercialization is needed.
Intensive Networking	✓ Active technology intermediary organizations provide a focal point for the state's biotechnology efforts. ✓ These organizations play a critical role in networking academic, industry, government, and nonprofit groups, encouraging cross-fertilization of ideas and opportunities that lead to joint endeavors.	✓ Colorado has several organizations that foster networking including the Colorado Biotechnology Assn., the Colorado Medical Device Assn., and the Colorado Alliance for Bioengineering. The Colorado Bioscience Park Aurora sponsors Bio Breakfasts and Bio West events that have been successful in showcasing Colorado bioscience companies.
Available Capital	✓ Best practice states and regions have created programs to address the commercialization, pre-seed, and seed financing gaps to help establish and build firms. ✓ Active informal angel networks investing in the biosciences. ✓ Investors include private, philanthropic, and public entities.	✓ Colorado has several local venture capital companies which invest in bioscience companies, including Sequel Ventures. ✓ A gap in pre-seed/seed funding stage exists. ✓ Limited angel networks are investing in the biosciences. ✓ Later stage funding will be necessary in future years as a critical mass of bioscience firms matures.

Table 8: Comparison of Colorado to Best Practice States and Regions on Key Success Factors (continued)

Factors of Success	Best Practice States/Regions	Colorado Situation
Discretionary R&D Funding	✓ Every major technology region in the U.S. has received significant federal discretionary funding. ✓ One or more federally designated centers exist that serve as anchors for the state or region's bioscience base.	✓ Colorado's universities have been very successful in competing for federal R&D dollars but less successful in obtaining industry R&D support. ✓ CSU is leading a regional effort to secure funding for a regional center of excellence in bioterrorism and emerging infectious diseases. ✓ Existing DOD, DOE, Commerce, HHS, and USDA federal labs and facilities exist on which to build relationships.
Talent Pool	✓ Talent increasingly provides the discriminating variable for states and regions to build comparative advantage. ✓ Educational institutions at all levels responsive to training students to meet the needs for bioscience workers at all skill levels including scientists, technicians, and production workers.	✓ Colorado has a highly educated population and available skilled workforce. ✓ Colorado attracts educated workers to relocate to the state. ✓ Colorado has not yet achieved a critical mass of companies which may discourage managers with bioscience experience to relocate to Colorado. ✓ Colorado's education and training providers produce high quality talent.
Specialized Facilities and Equipment	✓ Leading bioscience regions have private markets that provide facilities offering space for bioscience companies. ✓ Specialized bioscience incubators and research parks are common. ✓ Access to specialized facilities and equipment, such as core labs, and animal facilities, is readily available.	✓ Colorado Bioscience Park Aurora is the first university affiliated park focused exclusively on the biosciences in the Western U.S. ✓ Colorado has other technology parks, including CSU's Centre for Advanced Technology and Foothills Campus that can accommodate bioscience companies. ✓ Colorado has a good supply of buildings that can be adapted for use by bioscience companies. ✓ BSL-3 facility and Animal Cancer Center at CSU.
Supportive Business Climate	✓ Incentives to encourage growth of technology-driven firms through modernized economic development tool kit. ✓ Tax structures generally leveled to treat technology-driven and manufacturing firms evenly. ✓ Established brand name/image around technology themes.	✓ Colorado has a favorable business climate with stable tax and regulatory policies. ✓ Colorado has few economic development assistance programs/tools to attract, retain, and grow bioscience firms. ✓ Colorado perceives itself as lacking a national presence in the biosciences. While this may not be true, a brand/image is needed.
Patience and Long-term Perspective	✓ Building a critical mass of bioscience firms takes many years or even decades. ✓ While the early technology pioneers took 25 years to develop, more recent examples such as Maryland and San Diego took 12 to 14 years to mature.	✓ Colorado has been successful in growing the state's technology economy, particularly in IT. ✓ Colorado does not have a history of long-term, sustained and continuous state investment in technology development.

BENCHMARKING COLORADO AGAINST LEADING, EMERGING AND DEVELOPING BIOSCIENCE CENTERS

To assess Colorado's competitive position vis-à-vis other states that have either an established or emerging bioscience sector or that are trying to develop a bioscience sector, Battelle benchmarked Colorado against the following six states: Minnesota, North Carolina, Oregon, Utah, Washington, and Wisconsin. The states were chosen to achieve a mix of national leaders, emerging regions, and regional competitors.

Benchmark States

- Minnesota
- North Carolina
- Oregon
- Utah
- Washington
- Wisconsin

It should be noted that several of the benchmark states have a long history of investment in the biosciences and as a result have research institutions that are nationally recognized as leaders in the biosciences. In this respect, their bioscience base is at a very different stage of development than that of Colorado. They are included in the analysis because the purpose of the benchmarking is not only to determine where Colorado stands in terms of the development of its bioscience sector but also to learn from the experiences of the other regions and states.

Bioscience Industry Base

Colorado has a significant and rapidly growing base of bioscience establishments with significantly more establishments than Wisconsin, Oregon, and Utah but ranking below North Carolina, Washington, and Minnesota. In 2002, Colorado had 604 bioscience establishments employing 17,681 workers, ranking 4th among the benchmark states in terms of total bioscience establishments (see Table 9). Bioscience is defined to include pharmaceuticals, organic chemicals, medical devices and instruments, and bioscience research and testing. In addition, the number of bioscience establishments in Colorado increased by 35 percent from 1998 to 2002, also ranking Colorado the 4th fastest growing bioscience sector among the benchmark states. In terms of bioscience employment, however, Colorado experienced the smallest increase (4 percent) between 1998 and 2002 among the benchmarks.

Table 9: Private Sector Bioscience Industry Data

	Bioscience Establishments, 2002	Est. % Change, 1998 - 2002	Bioscience Employment 2002	Emp. % Change, 1998-2002	Location Quotient, 2002	Employees/ Establishment 2002
Colorado	*604*	*35%*	*17,681*	*4%*	*0.87*	*29*
Minnesota	716	21%	33,488	9%	***1.22***	47
North Carolina	785	47%	40,425	48%	1.17	51
Oregon	370	15%	7,358	8%	0.53	20
Utah	349	36%	16,941	31%	***1.80***	49
Washington	719	47%	16,675	12%	0.71	23
Wisconsin	491	20%	17,773	21%	0.72	36
United States	*4,011*	*32%*	*1,205,732*	*11%*	*1.00*	*301*

Note: Bold italics indicate significant concentrations (location quotients equal to or greater than 1.2).
Source: Dun & Bradstreet *MarketPlace* 19981995 (Q4) and 2002 (Q42001 (Q2), Battelle calculations. Bioscience is defined to include: drugs pharmaceuticals (SIC 2833-2836), organic chemicals (SIC 2869, 2873-2875, 2879), medical devices and instruments (SIC 3559-9922, 3821, 3826, 3841-, 3842, 3845), and bioscience research and testing (SIC 8731-01, 8731-9902, 8733-01, 8734-9903, 8734-9908, 8734-9910, and part of 8071 in Georgia only).

Only two of the benchmarks, Utah and Minnesota, have a specialization in the biosciences, although several of the benchmarks, including Colorado, have specializations in one or more bioscience subsectors (as the following section will describe). Utah is 80 percent more concentrated in the biosciences and Minnesota is 22 percent more concentrated in the biosciences than the nation. While Colorado is 13 percent less concentrated in the biosciences than is the nation, the state has a higher concentration than do Wisconsin, Washington, and Oregon.

Colorado's bioscience sector is comprised primarily of firms in two subsectors, medical device and instruments and research and testing. The benchmark states vary greatly in the makeup of their bioscience clusters. In Colorado, two subsectors, medical devices and instruments and research and testing account for about three-quarters of the state's bioscience establishments, accounting for 50 percent and 23 percent of bioscience establishments respectively. The drugs subsector accounts for 19 percent of bioscience establishments, and organic and agricultural chemicals for eight percent. In contrast, North Carolina's bioscience establishments are spread across the four sectors, with 35 percent in medical devices and instruments, 28 percent in research and testing, 23 percent in drugs, and 15 percent in organic and agricultural chemicals. Utah, at 26 percent, has the largest percentage of its bioscience establishments in the drugs subsector, and Washington has the largest percentage, 34 percent, in the research and testing subsector. Figures 13 and 14 portray the bioscience clusters of the benchmark states in terms of establishments and employment by industry subsector.

Figure 13: FY 2002 Bioscience Establishments by Subsector

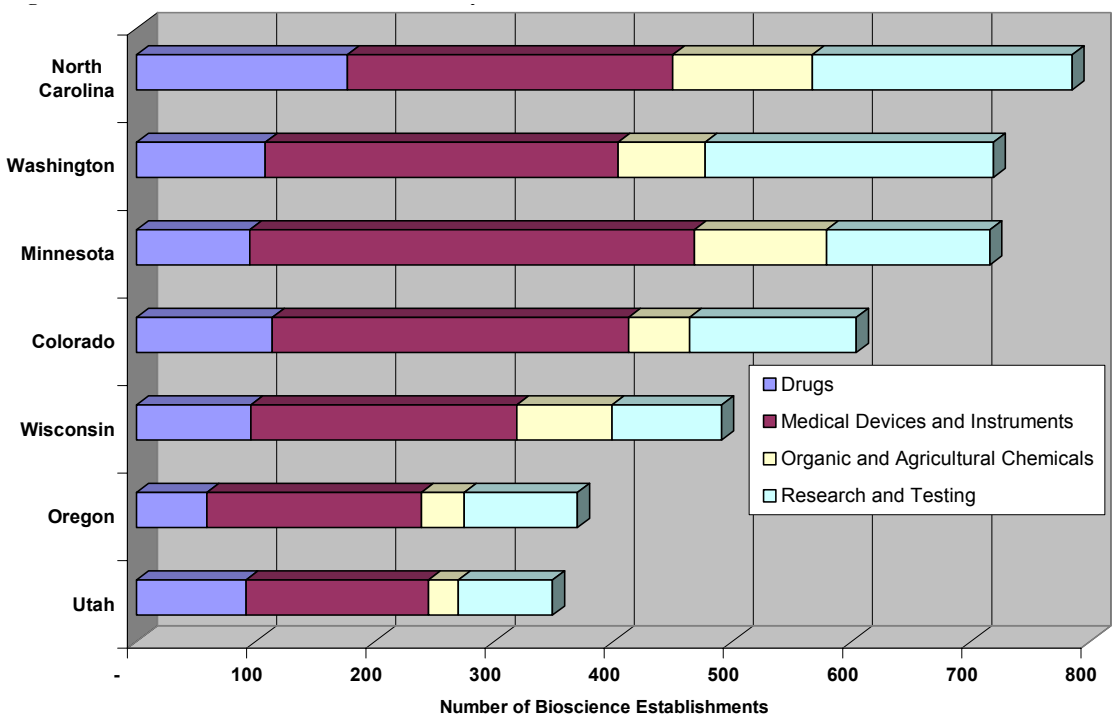
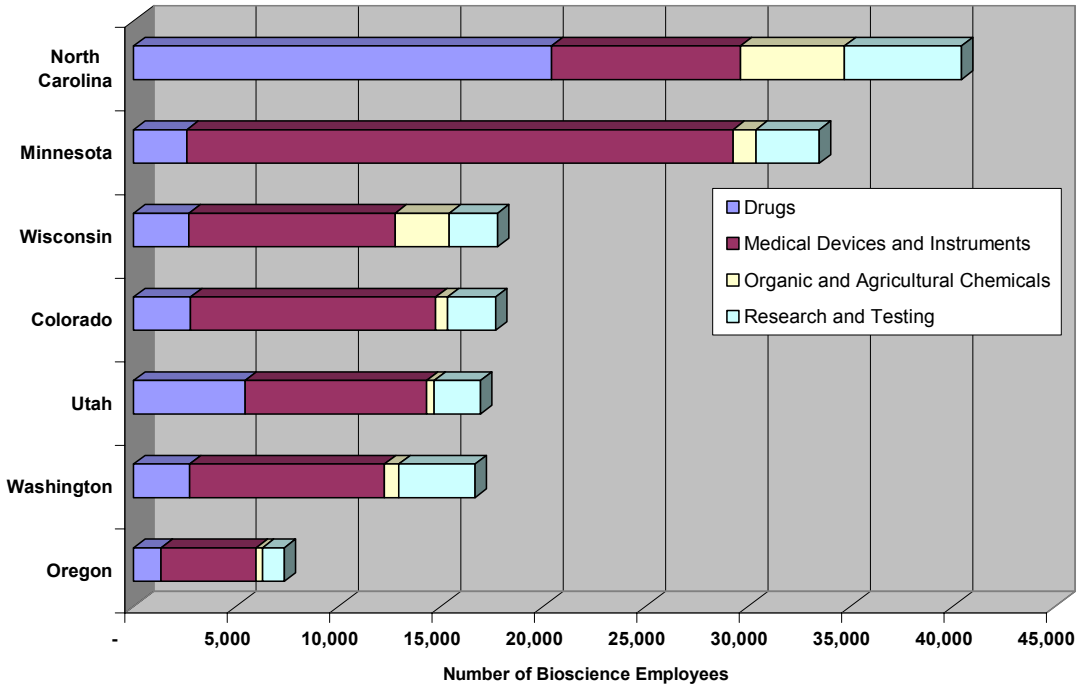


Figure 14: FY 2002 Bioscience Employment by Subsector



The establishment and employment growth in the medical device and research and testing sectors in Colorado have resulted in a growing specialization within these fields. Table 10 displays location quotients for each industry subsector by state. Location quotients are a common measure of the concentration of a particular industry or industry sector in a region relative to a reference area. A location quotient greater than 1.0 signifies that the region is relatively concentrated in the particular industry, whereas a location quotient less than 1.0 signifies relative under representation. States with a location quotient greater than 1.2 are considered to have a specialization in that particular industry. Colorado has a specialization in medical devices and is poised to develop a specialization in research and testing if the growth of this sector continues. Among the benchmarks, Oregon and Wisconsin have not yet developed a specialization in any of the subsectors. Utah has developed specializations in the drugs, medical devices and instruments, and research and testing subsectors.

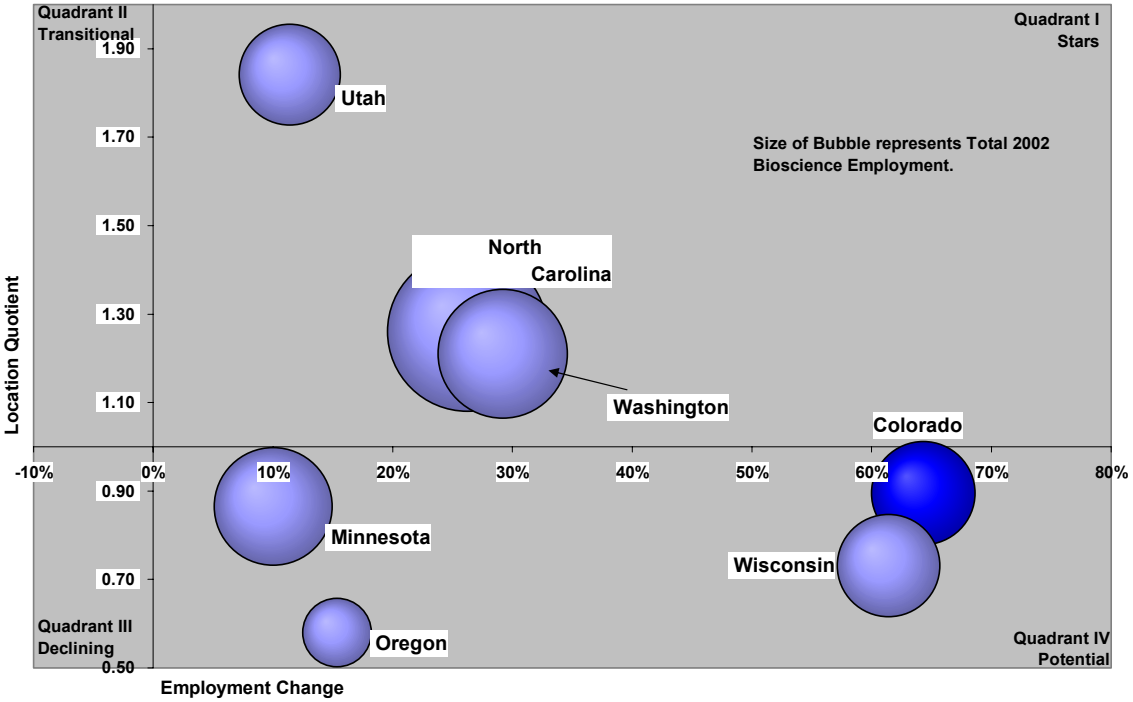
Table 10: 2002 Private Sector Bioscience Subsector Employment Concentrations (Location Quotients) and Employment Growth, 1998–2002

	Drugs		Organic Chemicals		Medical Devices & Instruments		Research & Testing	
	LQ	% Emp Ch	LQ	% Emp Ch	LQ	% Emp Ch	LQ	% Emp Ch
Colorado	*0.38*	*3%*	*0.22*	*23%*	***1.52***	*-5%*	*0.88*	*95%*
Minnesota	0.27	31%	0.32	21%	**2.53**	7%	0.87	10%
North Carolina	**1.65**	66%	1.14	98%	0.69	16%	**1.26**	26%
Oregon	0.27	30%	0.17	-38%	0.86	6%	0.58	15%
Utah	**1.62**	63%	0.30	5%	**2.44**	24%	**1.84**	11%
Washington	0.33	-14%	0.23	-27%	1.05	21%	**1.21**	29%
Wisconsin	0.31	53%	0.84	10%	1.06	12%	0.73	61%
United States	*1.00*	*25%*	*1.00*	*-8%*	*1.00*	*2%*	*1.00*	*34%*

Note: Bold italics indicate significant concentrations (location quotients equal to or greater than 1.2).
Source: Dun & Bradstreet MarketPlace 1998 (Q4) and 2002 (Q4), Battelle calculations. Bioscience is defined to include: drugs pharmaceuticals (SIC 2833-2836), organic chemicals (SIC 2869, 2873-2875, 2879), medical devices and instruments (SIC 3559-9922, 3821, 3826, 3841-, 3842, 3845), and bioscience research and testing (SIC 8731-01, 8731-9902, 8733-01, 8734-9903, 8734-9908, 8734-9910, and part of 8071 in Georgia only).

Colorado's research and testing subsector, while not yet a specialization, is growing more rapidly than any of the benchmarks. As Figure 15 depicts, Colorado is roughly 10 percent less concentrated in the research and testing subsector than the U.S. yet had the highest employment growth among the benchmarks from 1998 to 2002. Wisconsin had the second highest employment growth during this five-year period growing 61.4 percent. The nation as a whole grew by only 34 percent.

Figure 15: Research and Testing Employment Size and Location Quotient, FY 2002 and Employment Change, FY 1998–2002



Bioscience R&D Base

Colorado has a significant academic research base but a smaller bioscience research base than most of the benchmarks. Between FY96 and FY 2000, Colorado universities spent approximately $2.6 billion on R&D, $1.2 billion of which was in the biosciences (see Table 11).

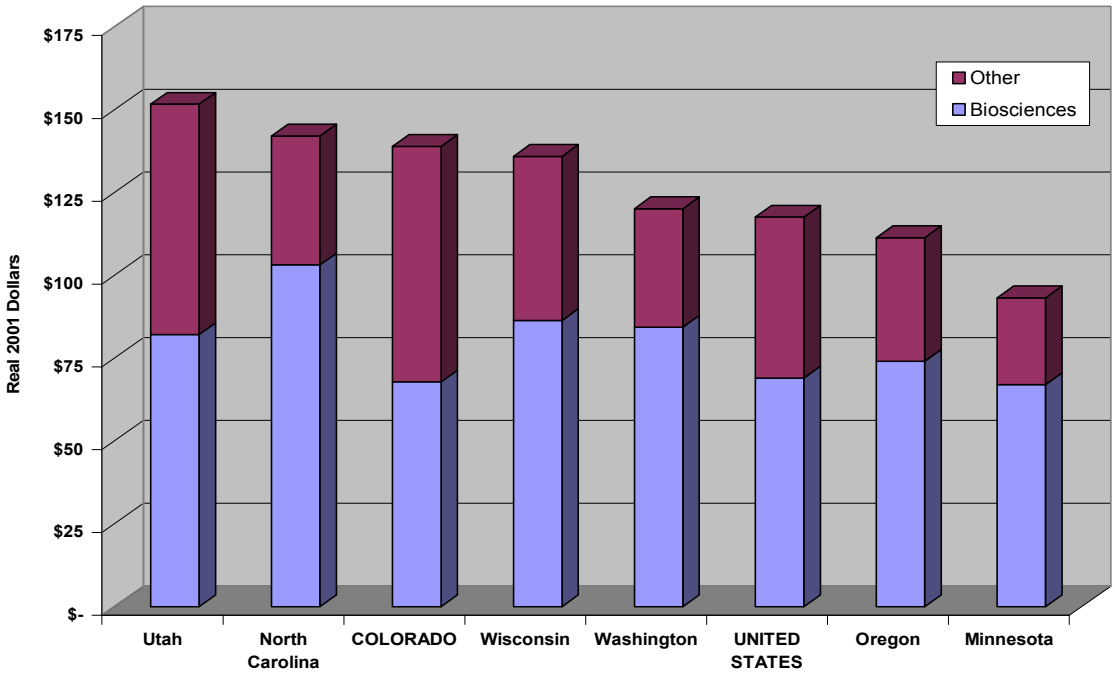
Table 11: Academic R&D, FY 1996–FY 2000

	Total Academic R&D	Total Bioscience R&D	Bioscience as % of All Academic R&D	Annual Bioscience R&D Per Capita	% Increase in Bioscience R&D, FY '96-'00
Colorado	*$2,614*	*$1,234*	*48.8%*	*$67.84*	*40.9%*
Minnesota	$2,056	$1,474	71.9%	$66.97	18.9%
North Carolina	$4,968	$3,516	72.6%	$103.14	42.0%
Oregon	$1,708	$1,109	66.5%	$74.04	32.1%
Utah	$1,399	$724	54.2%	$82.12	64.3%
Washington	$3,074	$2,060	70.2%	$84.33	33.8%
Wisconsin	$3,062	$1,898	63.6%	$86.36	38.7%
United States	*$143,404*	*$81,633*	*58.7%*	*$69.04*	*35.7%*

Note: Bioscience R&D dollar amounts are millions of real 2000 dollars. Source: National Science Foundation, Survey of R&D Expenditures at Universities and Colleges; United States Census Bureau (population); Battelle calculations.

In terms of total academic R&D expenditures, Colorado ranks fourth among the benchmarks behind North Carolina, whose universities spent $5 billion, and Washington and Wisconsin, whose universities spent $3 billion during the same time period. On a per capita basis, Colorado ranked third among the benchmarks, in terms of total R&D expenditures (see Figure 16).

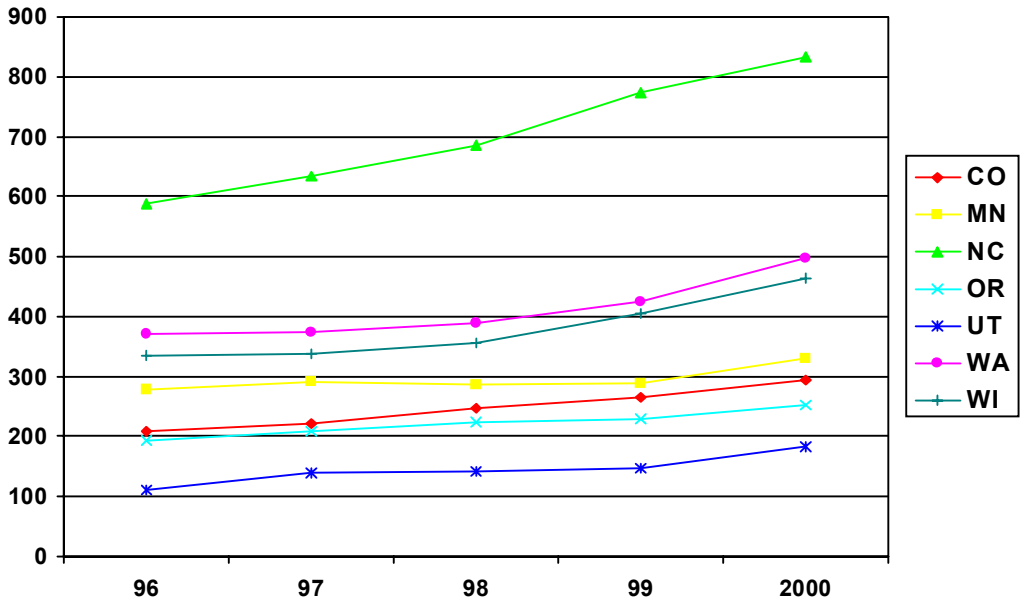
Figure 16: Academic R&D per Capita, FY 2000



Colorado's total bioscience R&D base is smaller than the majority of the benchmarks, but growing rapidly. In terms of bioscience R&D, Colorado ranks fifth among the benchmarks, behind Minnesota, North Carolina, Washington, and Wisconsin. This is a result, in part, of the fact that a smaller percentage of Colorado's R&D base is in the biosciences compared to both the benchmarks and the nation. In Colorado, approximately 49 percent of the state's total research base is in the biosciences, whereas biosciences accounts for 59 percent of total R&D nationally and 72 percent of R&D in Minnesota and North Carolina. This may reflect the fact that Colorado has been more effective in attracting R&D dollars in engineering and the physical sciences, key areas that support the biosciences, than have the benchmarks.

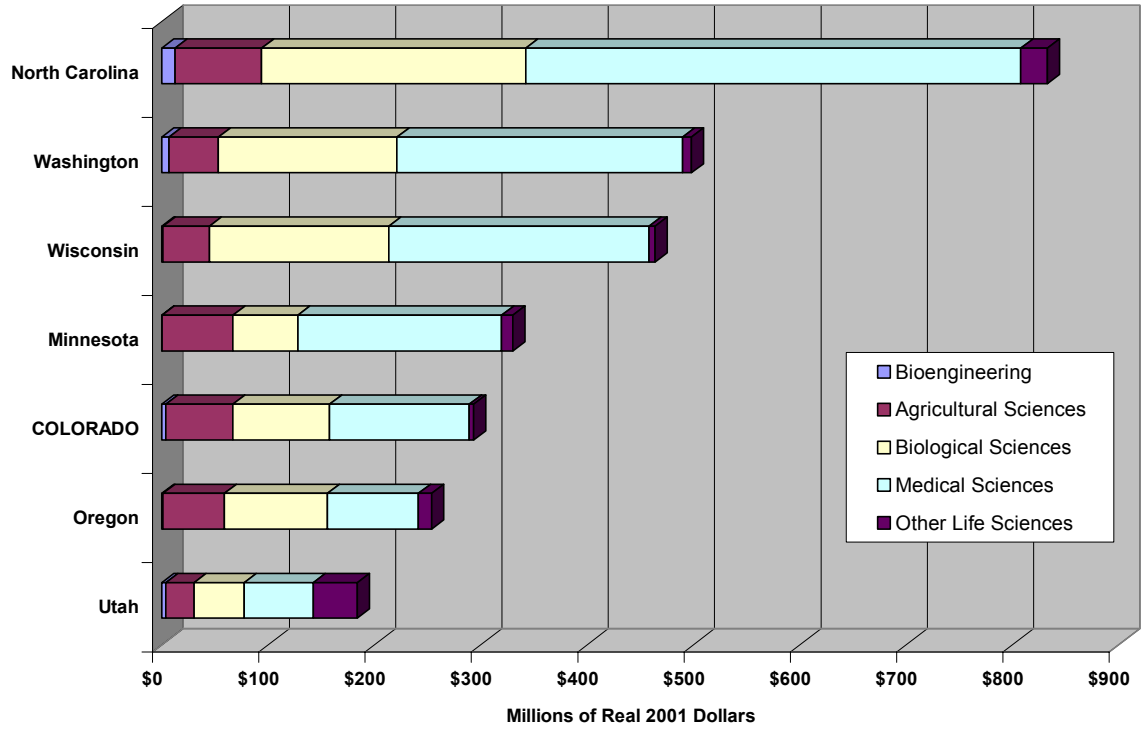
Colorado's bioscience research base, however, grew more rapidly than all but two of the benchmarks, and exceeded the national growth rate, in the 1996–2000 time period. During this five year period, Colorado's bioscience R&D expenditures increased by 41 percent as compared to a national increase of 36 percent. Of the benchmarks, the only state with a significantly larger increase in bioscience funding was Utah, which experienced a 64 percent increase in bioscience R&D during this time period. Figure 17 shows annual academic bioscience research for each of the benchmarks for the FY 1996–FY 2000 time period.

Figure 17: Total Academic Bioscience R&D Expenditures, FY 1996 - 2000



The states also differ in the make up of their bioscience research bases. Colorado's bioscience research base is diversified with 45 percent in the medical sciences, 31 percent in the biological sciences, and 21.5 percent in the agricultural sciences. Compared to the nation, Colorado's bioscience research base is less concentrated in medical sciences, which accounts for 51 percent of U.S. bioscience R&D, and somewhat more concentrated in agricultural sciences, which constitutes only 12.3 percent of U.S. bioscience R&D (see Figure 18).

Figure 18: Academic Bioscience R&D by Discipline, FY 2000



While Colorado's bioscience R&D expenditures grew rapidly, the state did not experience the same increase in NIH awards, often considered the "gold standard" of bioscience R&D funding. Between FY 1997 and FY 2001, Colorado's total NIH awards increased by 32 percent as compared to a national increase of 45.3 percent during the same time period (see Table 12 and Figure 19). Increases in NIH funding within the benchmarks ranged from a high of 52 percent in Utah to a low of 42.5 percent in Wisconsin.

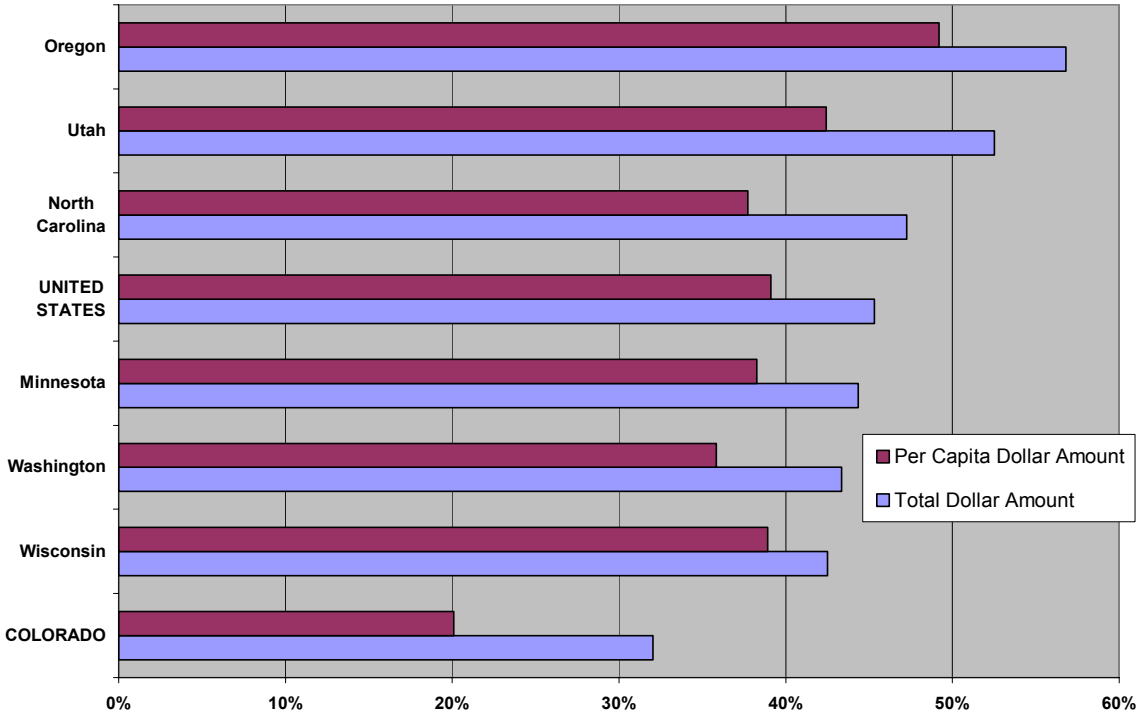
Table 12: National Institutes of Health Awards, FY 1997-2001

	FY 2001			% Change FY 1997-2001	
	Grants	Amount	Per Capita	Amount	Per Capita
Colorado	*890*	*$265.1*	*$60.00*	*$32.00*	*20.1%*
Minnesota	957	$325.4	$65.43	$44.30	38.3%
North Carolina	1,726	$689.1	$84.18	$47.30	37.7%
Oregon	652	$205.5	$59.17	$56.80	49.2%
Utah	405	$130.5	$57.49	$52.50	42.4%
Washington	1,415	$621.6	$103.82	$43.30	35.8%
Wisconsin	878	$282.2	$52.25	$42.50	38.9%
United States	*46,387*	*$16,647.3*	*$58.45*	*$45.30*	*39.1%*

Note: FY 2001 amounts are millions of real 2001 dollars.

Source: National Science Foundation, Survey of R&D Expenditures at Universities and Colleges; United States Census Bureau (population); Battelle calculations.

Figure 19: percentage of Change in NIH Awards, Total and per Capita, FY 1997–2001

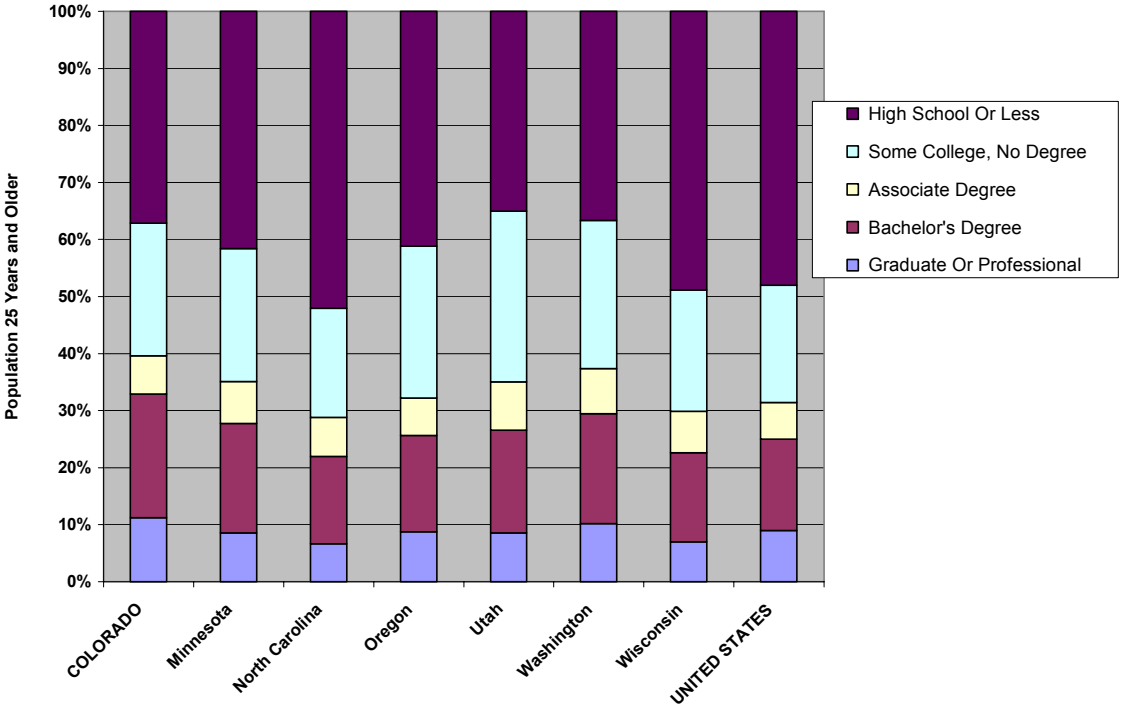


This may be due, in part, to the fact that Colorado has fewer research institutions competing for NIH awards than do some of the benchmark states which have multiple medical schools and public and private research universities with strong bioscience programs. On an institutional basis, the University of Colorado Health Sciences Center (UCHSC) ranked 20th in the number of NIH awards granted to medical schools in FY 2001 just above Harvard Medical School which ranked 21st. In addition, UCHSC ranked 8th in NIH awards to public medical schools. In the past five years, funding for the UCHSC has nearly doubled from $150.5 million to $248.6 million, with an average growth of 14.2 percent per year during the five year period.

Workforce and Talent Pool

Colorado has the most highly educated population among the benchmarks. In 2000, 11.25 percent of Colorado's population aged 25 and older held graduate or professional degrees as compared to nine percent nationally. Among the benchmark states, only Washington, with 10.2 percent of its population holding graduate or professional degrees, exceeded the national average. In addition, one-third of Colorado's population holds bachelor's or higher degrees. Nationally, 25 percent of the population holds a bachelor's or higher degree. Most of the benchmarks are near the national average, with the exception of Washington where 30 percent of the population has a bachelor's or higher degree and North Carolina where only 22 percent of the population has a bachelor's or higher degree (see Figure 20).

Figure 20: Educational Attainment by State, 2000 Census Estimates



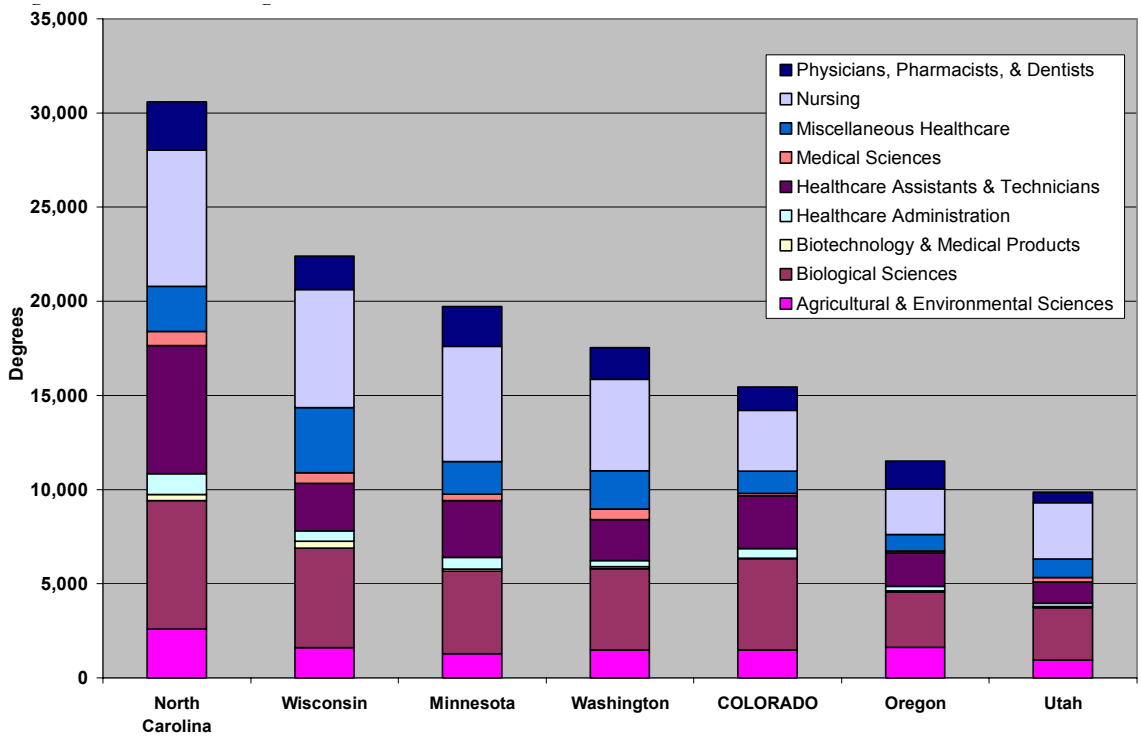
Colorado institutions of higher education awarded approximately 15, 000 bioscience degrees during the three year period between 1999 and 2001. On a per capita basis, Colorado ranked 5th among the benchmark states in terms of bioscience degrees awarded. North Carolina produced the greatest number of bioscience graduates and Utah produced the greatest number on a per capita basis (see Table 13 and Figure 21).

Table 13. Bioscience Degrees, All Levels, 1999-2001

	Total Bioscience Degrees Awarded	Degrees Per 1,000 Capita
Colorado	15,442	1.19
Minnesota	19,723	1.33
North Carolina	30,584	1.26
Oregon	11,509	1.12
Utah	9,859	1.47
Washington	17,540	0.99
Wisconsin	22,400	1.39

Sources: National Center for Education Statistics, COOL (College Opportunities On-Line) Data; United States Census Bureau (population), Battelle calculations.

Figure 21: Bioscience Degrees Awarded, FY 1999–2001



Risk Capital

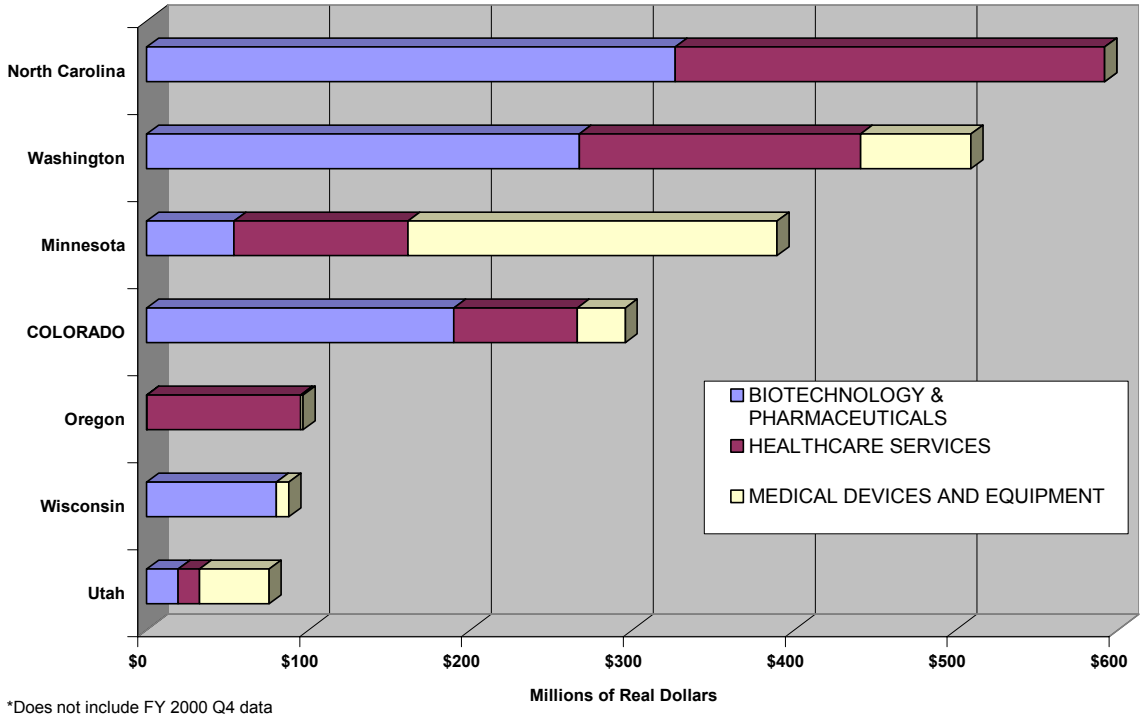
Colorado companies have been successful at attracting venture capital investments. In 2000, Colorado ranked 3rd in the country in terms of venture capital invested as a percentage of gross state product.[22] Colorado bioscience companies have succeeded in raising venture capital as well. Between 1997 and 2002, Colorado bioscience companies received $295.6 million in venture capital, two-thirds of which was invested in biotechnology and pharmaceutical companies.

[22] The State New Economy Index, http://www.neweconomyindex.org/states/2002/05_innovation_06.html

Twenty-six percent was invested in health services and 10 percent in medical device companies (see Figure 22).

Among the benchmark states, only Minnesota, North Carolina, and Washington received more bioscience venture capital investment than did Colorado, and all of these states received significantly higher amounts of bioscience venture capital than did Oregon, Wisconsin and Utah.

Figure 22: Bioscience Venture Capital, FY 1996–2002 Q2*



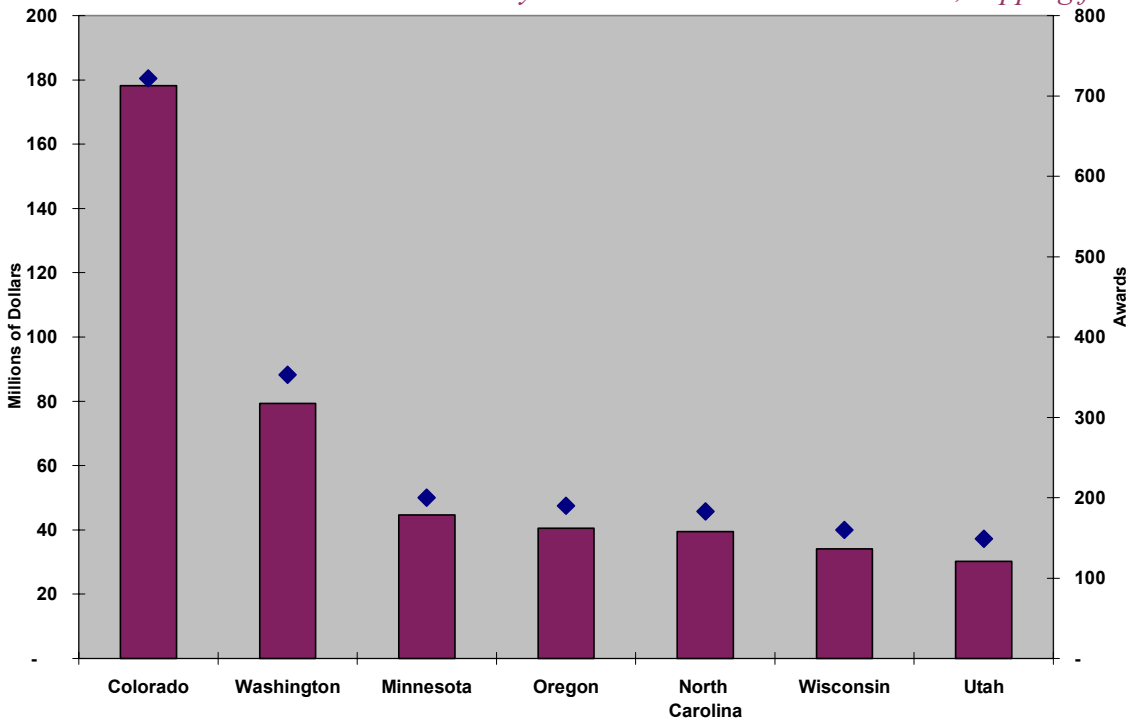
*Does not include FY 2000 Q4 data

Colorado outperforms all of the benchmarks in SBIR and STTR funding. Other important sources of risk capital are the federal Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) programs. They require all federal agencies with annual extramural research and development budgets of more than $100 million to set aside 2.5 percent of those monies to competitively fund innovative research conducted by small businesses. Since it was initiated in 1982, the SBIR program has grown to become the single largest source of competitive early-stage research and technology development funding in the country for small businesses. Today, the SBIR program awards more than $1 billion annually.

In terms of total SBIR and STTR awards from all federal agencies, Colorado outperforms all of the benchmarks in terms of total awards and increase in awards during the FY 1999–2001 time periods (see Figure 23).

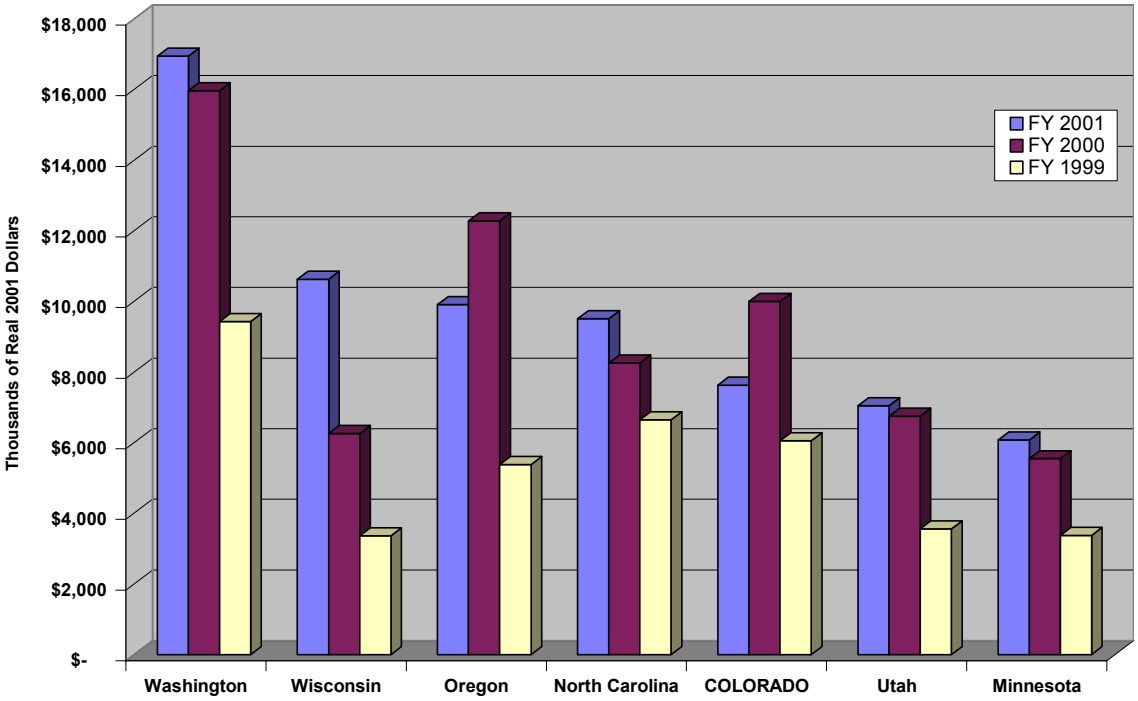
Figure 23: All SBIR/STTR Awards, FY 1999–2001

Colorado does not rank as well when only NIH SBIR awards are examined, slipping from



1st to 5th. One way to gauge the level of bioscience research occurring in a state is to examine the number of NIH and Department of Agriculture (DOA) SBIR awards going to a particular region or state. Figure 24 displays the awards made by NIH and DOA through the SBIR and STTR programs for FY 1999, FY 2000, and FY 2001. During this time period, Colorado received $23.7 million, averaging $6–10 million per year. Washington clearly was the leader among the benchmarks receiving $42.4 million during the three year period. Colorado received slightly fewer awards than did Oregon ($27.6 million) and North Carolina ($24.4 million), but performed better than Wisconsin ($20.3 million), Utah (17.4 million) and Minnesota ($15.4 million). In FY 2001, 15 Colorado companies received a total of 18 Phase I awards totaling $2.2 million and 10 Colorado companies received 15 Phase II awards totaling $5.5 million. One company, Boulder Biotechnology Inc., accounted for five Phase II awards totaling $1.6 million.

Figure 24: NIH SBIR and STTR Awards, FY 1999–2001



Knowledge Transfer and Commercialization

In addition to having a strong bioscience research base, regions with strong bioscience sectors have established mechanisms that promote the transfer of knowledge from universities and laboratories to industry. Much of Silicon Valley's success, for example, is attributable not only to the world-class research conducted at Stanford University, but also to Stanford's policy of encouraging its faculty and students to commercialize research that they developed. Measuring a state's capacity to realize commercialization benefits from research findings is difficult, if not impossible. However, a number of data points can be used as indicators of the vitality of a state's technology transfer activity. These include:

- Invention disclosures
- Patent applications filed
- Patents issued
- Licenses executed
- Start-up companies formed.

Bioscience research institutions in the State of Colorado tend to rank below the national average on a number knowledge transfer metrics. The Association of University Technology Managers (AUTM) conducts an annual survey that collects information on invention disclosures and patenting and licensing activities from universities throughout the United States. Not all universities participate in the survey. AUTM's FY 2000 survey included data for approximately 140 universities, including Colorado State University. The University of Colorado did not participate in the 2000 survey but has supplied FY 2000 data that is included in the table below.

Table 14 shows measures of technology transfer for the University of Colorado and Colorado State University. Both universities rank at or slightly below the median on most of the measures.

Table 14: Colorado Universities Technology Transfer Activities: FY 2000

Metric	University of Colorado FY 2000	Colorado State University FY 2000	AUTM Median For Universities	AUTM Top Quartile for Universities
Sponsored Research Expenditures (2001 dollars)	***$353,528,000***	$157,547,913	$92,722,623	$193,984,766
Invention Disclosures Received	93	45	34	87
Patent Applications Filed	74	27	25	63
Patents Issued	25	7	10	24
Licenses & Options Executed	21	7	11	24
Licenses & Options Generating Income	55	28	22	45
Gross License Income	$1,936,905	$621,023	$998,451	$4,119,288
Startups	2	2	1	3
Disclosures per $10 M Sponsored R&D	***2.63***	2.86	4.22	5.80
Patents Issued per $10 M Sponsored R&D	***0.71***	0.44	1.10	1.67
Licenses Executed per $10 M Sponsored R&D	***0.59***	0.44	1.13	1.85
License Income per $10 M Sponsored R&D	***$54,788***	$39,418	$85,817	$276,519
Average Revenue per License	$35,216	$22,179	$42,754	$93,951
Startups per $10 M Sponsored R&D	***0.06***	0.13	0.09	0.21
Startups per License Executed	0.10	0.29	0.08	0.18

Note: Italics and Bold for The University of Colorado's Sponsored Research Expenditure's for FY 2000 was imputed from NSF data as this figure was unavailable from AUTM.

In addition, the University of Colorado recently conducted a benchmarking in which they compared themselves to top public universities with a medical center. Included in the benchmarking were the Universities of Arizona, Illinois, Michigan, Minnesota, Penn State, North Carolina, Washington, and Wisconsin. Among these universities Colorado ranked third in federal research dollars. On measures of technology transfer, however, the analysis showed that "CU is underperforming in technology transfer relative to peers."[23] The University has significantly increased its commitment to technology transfer and set a goal of that the Technology Transfer Office will be recognized as the best among public universities by 2010.

National Jewish Medical and Research Center Hospital also generally ranks at or below the median on technology transfer statistics as compared to hospitals that respond to the AUTM survey (see Table 15). National Jewish does rank highly in terms of patents issued per $10 million of sponsored research, a category in which it greatly exceeds even the top quartile of hospitals.

[23] *2002 Strategic Plan: Building a World-Class Technology Transfer Operation* University of Colorado System, June 2002.

Table 15: National Jewish Medical and Research Center Hospital Technology Transfer Activities: FY 2000

Metric	National Jewish Medical and Research Center Hospital	AUTM Median For Hospitals	AUTM Top Quartile for Hospitals
Sponsored Research Expenditures (2001 dollars)	$43,448,086	$85,351,513	$163,327,358
Invention Disclosures Received	18	43	119
Patent Applications Filed	25	27	57
Patents Issued	13	12	19
Licenses & Options Executed	8	12	33
Licenses & Options Generating Income	16	21	39
Gross License Income	$313,302	$1,130,652	$3,830,444
Startups	0	2	5
Disclosures per $10 M Sponsored R&D	4.14	4.27	6.13
Patents Issued per $10 M Sponsored R&D	2.99	1.27	1.82
Licenses Executed per $10 M Sponsored R&D	1.84	1.49	2.25
License Income per $10 M Sponsored R&D	$72,110	$93,553	$459,734
Average Revenue per License	$19,581	$43,025	$121,420
Startups per $10 M Sponsored R&D	0.00	0.14	0.28
Startups per License Executed	0.00	0.09	0.25

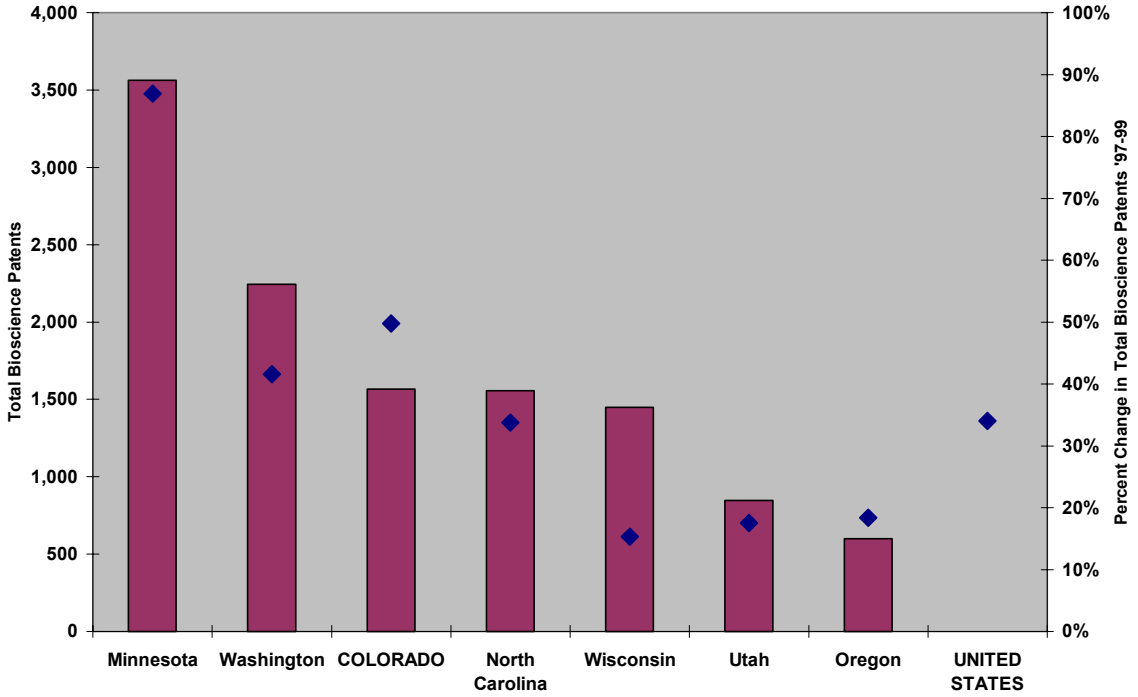
The number of bioscience patents issued in Colorado has increased dramatically over the last several years, as sign of innovative growth. Another indicator of the ability of a region to turn discoveries into commercial products is the number of patents issued. Colorado ranks third among the benchmarks in terms of the number of biotech-related patents[24] awarded between FY 1997 and 2001. Colorado experienced almost a 50 percent increase in the number of bioscience patents issued during this time period, exceeding the national growth rate of 34 percent (see Table 16 and Figure 25).

Table 16: Biotech Related Patents, FY 1997–2001

	Biotech- Related Patents FY01	Total Patents FY97–01	% Change Patents FY97–01
Colorado	*343*	*1,566*	*49.8%*
Minnesota	841	3,563	86.9%
North Carolina	345	1,556	33.7%
Oregon	116	599	18.4%
Utah	181	846	17.5%
Washington	480	2,243	41.6%
Wisconsin	271	1,449	15.3%
United States	*17,315*	*81,760*	*34.0%*

[24] "Biotech-related" refers to a definition adapted from the U.S. Patent and Trademark Office that may differ from the definition of "bioscience" used in this report. Biotech-related patent classifications as defined by the U.S. Patent and Trademark Office are detailed in Appendix A.

Figure 25: Total Number of Bioscience Patents Issued by State, FY 1997–2001 with Percent Change in Bioscience Patents, FY 1997–2001



Tax Policy

States traditionally have used tax policy to encourage companies to locate or grow within the state. Many development incentives, however, provide a subsidy or credit based on employment levels, and, as such, tend not to benefit bioscience and technology companies that have small numbers of employees but high intellectual capital. Some states are enacting changes in tax policy designed to provide benefits to technology firms, including bioscience firms.

No state among the benchmarks has implemented tax incentives or regulatory reform aimed specifically or exclusively at bioscience firms, but virtually all have determined that bioscience sectors are included among those targeted by initiatives aimed at R&D in general. Typical tax initiatives include:

- Treatment of R&D equipment on a par with manufacturing equipment with respect to exemptions or abatements from sales or use tax on its purchase.
- Treatment of R&D equipment on a par with manufacturing equipment with respect to exemptions or abatements from tax on its value as tangible personal property (where such tax is levied on businesses).
- Tax credits for R&D expenditure—either incremental of a baseline or non-incremental—and carry forwards and/or sale of unused credits.

Some states seeking to grow bioscience firms have enacted provisions that allow firms to carry forward and/or sell R&D tax credits and in some instances net operating losses (NOLs). None of the states in the benchmark set, however, have enacted such provisions.

Specialized Facilities

Ensuring that the private marketplace offers the right amount and type of space suitable for the development and growth of bioscience firms has been a major challenge for emerging bioscience regions. No data are available to determine the square footage of wet lab space available in different states; however, a survey of state government initiatives in biotechnology[25] found that:

- Nine states, including Wisconsin of the benchmark states, have used traditional economic development programs to fund facilities for bioscience companies, and two states, Arkansas and Connecticut, have programs specifically targeted to assisting bioscience companies with facilities development.
- Nine states have research parks focused exclusively on bioscience companies.
- Fifteen states have publicly sponsored bioscience incubators.

In two of the benchmark states, North Carolina and Wisconsin, the creation of research parks and incubators have played a key role in developing the states' technology base. In addition to Research Triangle Park, North Carolina has created Centennial Campus, a dual use campus and university research park at NC State University, and a Piedmont-Triad Research Park, which is expanding in Winston Salem and hosts certain activities of Wake Forest University's Bowman Gray School of Medicine. Neither of these parks, however, focuses exclusively on the biosciences. Wisconsin's University Research Park, which was created in 1984, now has 34 buildings housing 102 companies and a business incubator. The development corporation that manages the research park is self-sufficient and pays taxes to the City of Madison, remitting any residential surpluses to UW-Madison research programs.

SUMMARY

The benchmarking analysis suggests that Colorado's bioscience infrastructure, while not as well developed as such recognized bioscience centers as North Carolina and Washington, is clearly developing. In addition, on most indicators Colorado outperforms Oregon and Utah, two regional competitors. The following factors indicate that Colorado's bioscience base has the potential to expand significantly.

- The state has a well-established medical device and instruments industry.
- The state's research and testing bioscience subsector is growing rapidly and may be on the verge of achieving a critical mass of such companies.
- Colorado's bioscience R&D base is growing rapidly.
- Colorado has a large pool of highly educated workers.
- Colorado bioscience companies have been successful in attracting venture investments.
- Colorado is generating new knowledge as reflected in the level of patenting activity.

The benchmarking analysis also points to some areas where improvement is needed. First, Colorado has not been competitive as a state in obtaining NIH awards, although the University of

[25] *State Government Initiatives in Biotechnology 2001*, Battelle and the State Science and Technology Institute, September 2001.

Colorado Health Science Center and Colorado State University have been competitive on an institutional basis with their respective peer institutions. Second, Colorado's research institutions have not been as successful in transferring and commercializing technology as their counterparts nationally.

Situational Analysis

Colorado is not alone in seeking to grow its bioscience industry cluster. States and regions across the country are focusing resources on creating an environment that will encourage and facilitate the growth of their bioscience sectors. To succeed, Colorado must build upon its comparative advantages as a location for bioscience companies and address any comparative disadvantages. The Battelle project team interviewed approximately 80 public and private leaders, bioscience company CEOs, entrepreneurs, venture capitalists, government officials and service providers to get their input on the strengths, weaknesses, opportunities and threats facing Colorado as the state seeks to grow a vibrant bioscience sector. This section of the report summarizes the team's findings obtained through interviews, small group discussions, focus groups, and review of secondary data.

COLORADO'S COMPETITIVE ADVANTAGES

A highly educated population and available skilled workforce. Colorado has one of the most highly educated populations among the 50 states. In 2000, 11.25 percent of Colorado's population aged 25 and older held graduate or professional degrees as compared to nine percent nationally. Colorado ranks first among the fifty states in the percentage of the population aged 25 and older that hold a bachelor's degree or higher (34.6 percent). Colorado also has a base of science and engineering workers ranking second in the nation in the percentage of scientists and engineers in the workforce (1999).

Dynamic entrepreneurial economy. Coloradoans support risk taking and embrace new opportunities. Evidence of Colorado's strong entrepreneurial culture is found in the fact that Colorado ranks extremely high in metrics that attempt to rank its level of entrepreneurial development. In the Progressive Policy Institute's The 2002 State New Economy Index, Colorado ranked fourth in the nation in economic dynamism, which is defined as a state's ability to foster the creation of new firms, support firms that innovate, and cultivate a culture that is epitomized by fast-growing, entrepreneurial companies. This dynamism ranking was comprised of several metrics.

- The number of jobs in gazelle companies (companies with annual sales revenue that have grown 20 percent or more for four straight years) as a share of total employment. In the gazelle category, Colorado ranked thirteenth in the nation in 2002.
- "Job churning," which is defined as the number of new start-ups and business failures combined as a share of all establishments. Steady growth in employment masks the constant churning of job creation and destruction, as less innovative and efficient companies downsize or go out of business and more innovative and efficient companies grow and take their place. While such turbulence increases the economic risk faced by workers, companies, and even regions, it is also a major driver of economic innovation and growth. Colorado ranked sixth in 2002.
- The number of initial public offerings (IPOs), a weighted measure of the value and number of initial public stock offerings of companies as a share of gross state product. In this category, Colorado ranked fourth in the nation in 2002.

In a study prepared by the Milken Institute for the California Technology, Trade and Commerce Agency's Division of Science, Technology and Innovation, Colorado ranked second after Massachusetts as the best positioned state to succeed in the technology-led information age.

Strengths

- Highly educated population and skilled, available workforce
- Dynamic, entrepreneurial economy
- Attractive life style and environment
- Attractive business climate
- Research institutions with strengths in selected bioscience areas
- Strong bioscience infrastructure
- Quality manufacturing companies that have mass customization capabilities

Attractive life style and environment. Colorado offers recreational opportunities and other amenities that offer a quality of life that many people, particularly highly educated, skilled technical workers, find attractive. While quality of life is a subjective factor, it is clear that Colorado's geography, climate, recreational and cultural amenities serve to draw people to the state. Between 1995 and 2000, the state's population grew by thirteen percent, much faster than the national rate of six percent. Colorado ranks third in net migration after Nevada and Arizona. Surveys conducted on behalf of the Colorado Office of Economic Development found that Denver is highly rated among young professionals as a place to work and as a relocation site.

Anecdotal evidence indicates that graduates of Colorado's institutions of higher education tend to want to remain in the state, in some cases taking positions for which they are overqualified in order to remain. A study conducted for the National Science Foundation, which examined interstate migration of recent science and engineering graduates, found that 57 to 66 percent of students that had received degrees in Colorado were working in the state after graduation. In addition, Colorado ranked in the top quartile of states in the degree to which the state is a net importer of science and engineering graduates.[26]

Attractive business climate. Overall, the business climate in Colorado is favorable with a stable tax and regulatory environment. Colorado has achieved an A rating on key measures of business climate during the last seven years, the only state in the country to achieve this ranking, as measured by the Corporation for Enterprise Development that ranks states in term of economic performance, business vitality and development capacity.[27]

[26] Louis Tornatzky, Ph.D., Denis Gray, Ph.D.,/Stephanie Tarant, and Julie Howe. *Where Have All the Student Gone: Interstate Migration of Recent Science and Engineering Graduates*. Southern Technology Council, February 1998.
[27] Corporation for Enterprise Development. *Development Report Card of the States 2002*. Washington D.C., December 2002.

Research institutions with strengths in selected bioscience areas. Colorado is a major source of university based scientific research—bringing substantial funding into the state—and outpacing the state's overall ranking in population. As discussed previously, Colorado's university research base in science fields totaled $559.7 million in FY 2000. This level of funding ranked Colorado 18th among the 50 states and the District of Columbia compared to its population rank of 24th in the nation. Bioscience research, which accounts for a substantial $273 million in total university research in Colorado, grew 31 percent from FY 1996 to FY 2000, compared to 27 percent for the nation.

Colorado is also home to the National Jewish Medical and Research Center, a private non-profit biomedical research institution. National Jewish ranked thirteenth among independent hospitals for NIH-funded biomedical research with a total of $26.7 million in NIH funding.

There are at least four federal laboratories with operations in Colorado: the National Oceanographic and Atmospheric Administration (NOAA) Environmental Technology Laboratory and the National Institute of Standards and Technology laboratory both located in Boulder, the National Renewable Energy Laboratory in Golden, and the Centers for Disease Control and Prevention (CDC) lab in Fort Collins. Other Colorado institutions that contribute to the state's bioscience base include Children's Hospital-Denver, the VA Medical Center-Denver, USDA and other related laboratories at the NRRC in Fort Collins.

Opportunities

- Well positioned to take advantage of niche market opportunities.
- Universities positioned to substantially increase bioscience R&D funding.
- University leadership committed to investing resources to facilitate commercialization of university developed technologies.
- Fitzsimons and other technology parks offer potential to develop bioscience hub.
- Potential opportunities for plant and animal-based pharmaceutical production.

Strong bioscience infrastructure. Colorado has developed research parks and facilities that can support bioscience companies at each stage of the business life cycle, from early stage start-up to established companies with manufacturing operations. The **Colorado Bioscience Park Aurora** is a 160 acre research park located adjacent to the new UCHSC/UCH campus at Fitzsimons. Formally affiliated with CU, the Bioscience Park is the first of its kind west of the Mississippi. The first research park building, the Bioscience Park Center, opened in October 2000. The Bioscience Park Center houses the Park's administrative offices and provides incubator space to start-up bioscience companies as well as built to suit space for expansion stage companies. The building currently houses 18 start-up bioscience companies and three academic groups. Companies locating in the Park will have access to scientific support services and facilities and the opportunity to enter into collaborative relationships with faculty and researchers at the UCHSC/UCH campus.

The Colorado State University Research Foundation, in conjunction with Everitt Enterprise of Fort Collins, has developed a multi-use technology park, known as the **Centre for Advanced Technology,** located directly south of the main campus of Colorado State University. The park currently houses and is expected to attract additional companies that wish to have a collaborative relationship with CSU. The Centre is home to the Natural Resources Research Center (NRRC) which is a campus of five buildings that house between 800 and 1000 federal employees. Companies housed at the Center include Atrix Laboratories, Inc. and Summit Plant Laboratories. **The University of Colorado Research Park** is located in Boulder and seeks to attract tenants

desiring a collaborative relationship with the university. The **CSU Foothills Campus** is currently in the early stages of development and also offers a new venue for bioscience industry.

Colorado has several incubators that provide support for start-up technology companies including bioscience companies, such as CTEK, CVC (Colorado Ventures Center), Colorado Springs Technology Incubator, and the Ft. Collins Virtual Incubator. Each of these incubators provides support to technology entrepreneurs and start-up companies. CTEK has some space available to house companies but their main focus is providing mentoring and advice to client companies. Colorado also has an inventory of existing buildings that can readily be converted for use by bioscience companies.

Quality manufacturing companies that have mass customization capabilities. One of the advantages Colorado has over even established bioscience areas is the ability to support the cluster at all stages of development from research and development through manufacturing and sales. Leading bioscience centers such as Boston and San Francisco are often not cost competitive for manufacturing. In Massachusetts, for example, only about 10 percent of the state's biotechnology companies are currently involved in manufacturing and of those, more than half do their manufacturing out of state.[28]

Colorado has a strong technology-based manufacturing sector. Colorado has more than 6,000 manufacturing companies with more than 205,000 Colorado employees. These firms produce a diverse mix of manufacturing products including high technology instruments, machinery, computer equipment, aerospace equipment, medical devices and pharmaceuticals. Colorado's strength in manufacturing means that the state will be able to capture the downstream, value added jobs that will be created by bioscience companies over the long run.

Weaknesses

- Industry base has not yet reached critical mass.
- Higher education and bioscience industry have weak record of connectivity and collaboration.
- Industries and universities in Colorado are not capturing the full potential commercialization of research findings.
- Lack of strong public sector initiatives in support of the bioscience industry.
- Lack of perceived national presence.

COMPARATIVE DISADVANTAGES

While Colorado is in a strong position to compete with other regions in developing its bioscience base, there are several areas in which Colorado is not as competitive as other regions with established or emerging biosciences bases. These include:

Colorado's bioscience industry base is at an early stage of development. Colorado has a rapidly growing research and testing (biotechnology) sector, with many small companies that have yet to introduce products in the market. Likewise drug and pharmaceutical establishments in Colorado employ an average of only 24 workers whereas nationally the average drug and pharmaceutical establishment employs 72 workers. These factors suggest that Colorado's bioscience sector has not yet reached the maturity of other leading bioscience centers. There is reason to believe however, that Colorado's drugs and pharmaceuticals sector will grow as more of Colorado's biotechnology research and testing firms mature.

[28] The Boston Consulting Group and the Massachusetts Biotechnology Council, *MassBiotech 2010*, 2002.

Higher education and bioscience industry have a weak record of connectivity and collaboration. In 2000, of a total R&D budget of $353.5 million at the University of Colorado system, only 2.6 percent came from industry. At Colorado State University, 4.3 percent of its 2000 R&D funding came from industry. Nationally, 7.2 percent of total university R&D funding at universities came from industry in 2000.[29] The lower percentage of funds coming from industry going to CU and CSU is due in part to the universities very successful track record in attracting federal R&D dollars. The one Colorado university with a significant percentage of its R&D funding coming from industry, albeit with a much smaller research budget of $21.8 million, is the Colorado School of Mines with 36.1 percent of its R&D funding coming from industry.

Industries and universities in Colorado are not capturing the full potential commercialization of research findings. Major improvements and changes are underway by the University of Colorado System and efforts continue at CSU and CSM to improve the management and transfer of intellectual property. Meanwhile, additional ways to move research toward commercialization, reduce to practice research findings, access capital, and provide mentoring by serial bioscience entrepreneurial managers will be needed to move university research findings into commercial products. The birth of new bioscience enterprises has remained strong in Colorado at the same time there has been an ongoing death of firms. As a result, Colorado has failed to build a critical mass as quickly as might be expected given its entrepreneurial culture and the size of its private venture capital base.

Threats

- Other states and regions are aggressively pursuing bioscience development.
- Other universities are pursuing biosciences as a key area of focus for their future.
- Lack of sufficient capital at the right stages may deter entrepreneurial start-ups from starting or growing in the state.
- Lack of support for Colorado's emerging bioscience companies may result in their decision to move out of the state.
- Colorado leaders must increase their knowledge and commitment to the biosciences if it is to become a key driver of the state's economic future.

Lack of strong public sector initiatives in support of the bioscience industry. While Colorado has undertaken a number of initiatives in the communications and information technology sectors in recent years, there has been less focus on biosciences with the notable exception of the new development at Fitzsimons and the Centre for Advanced Technology and regional biocontainment lab facility at CSU.

Lack of perceived national presence. Representatives of Colorado's bioscience sector indicated in interviews that a disadvantage of Colorado as a location for bioscience companies is the fact that the state does not have a national image as a center of the biosciences. Yet many reports in the media often cite Colorado as an emerging bioscience region. There appears to be a need to brand Colorado in the biosciences and to increase.

[29] Source: National Science Foundation/Division of Research Science Statistics, Survey of Research and Development Expenditures at Universities and Colleges.

Themes and Actions: An Action Agenda to Position Colorado in the Biosciences

PROPOSED APPROACH

Colorado should build its bioscience base by focusing on its unique assets and capabilities. These include first and foremost its entrepreneurial culture and its strong base of research institutions. It is recommended that Colorado grow the biosciences by:

- Nurturing home grown businesses;
- Creating excellence in selected bioscience research areas; and
- Addressing the complexity of the research and industry enterprise through cooperative endeavors.

Build Our Own

Colorado has a history of strong entrepreneurial development, ranking second among the fifty states in terms of new business start-ups in 2000. Colorado's bioscience sector consists primarily of small companies that have been started in Colorado. In 2000, Colorado's research and testing (biotechnology) companies had an average of 17 employees while the state's drugs and pharmaceutical companies had an average of 24 employees. Colorado has a rapidly growing base of research and testing (biotechnology) companies that, as they mature, will lead to growth in the state's drug and pharmaceuticals sector.

Colorado can foster the creation and growth of new start-up companies by providing support for entrepreneurs and emerging bioscience companies, ensuring the availability of venture capital in all stages of a company's life cycle and improving the commercialization of university inventions.

Create Research Excellence in Selected Bioscience Areas

As discussed above, Colorado's bioscience research base is very diverse. A tighter focus on selected niches will be needed if Colorado is to develop concentrated strengths to catch up with leading bioscience regions. It is recommended that Colorado's research institutions, working in partnership with each other and with industry, develop capabilities around a number of bioscience technology platforms. Initial targets for the development of such platforms include:

Pharmaceutical Biotechnology – This focus area would build on Colorado's considerable resources in basic biological sciences and expertise in specific fields of medicine and take advantage of the University of Colorado's Center for Pharmaceutical Biotechnology and Colorado State University's Bioprocessing Center. It would also support Colorado's existing base of companies involved with drug development and drug delivery systems.

Medical Devices and Bioengineering – Colorado is already home to a concentration of medical device companies and the state's research institutions conduct significant research in bioengineering. The CU College of Engineering estimates that the College conducts $6 million in

bioengineering research annually. CSU and CSM also have research strengths in particular areas of bioengineering. This focus area would build on Colorado's competencies in biomaterials, BioMEMS/nano-technology.

Plant and Agricultural Biotechnology – Colorado is well positioned to assume leadership within the fast moving field of plant biotechnology. Existing Colorado plant bioscience assets include the National Seed Storage Laboratory at CSU, CSU's Departments of Bioagricultural Sciences and Pest Management, Soil and Crop Sciences, Biology, and program in Horticultural Biotechnology, and the University of Colorado's strengths in plant physiology.

Biosecurity – The field of biosecurity is likely to experience tremendous growth as the United States and the world responds to a wide array of bioweapon threats. CSU and the CDC's labs in Fort Collins are leading a proposal that includes a number of regional research institutions for a regional center of excellence in bioterrorism and emerging infectious disease. Whether or not this center is funded, Colorado has existing assets, including the CDC lab in Fort Collins, which could contribute to developing a counter-terrorism research and commercial sector.

Over the longer term, additional focus areas that appear to have market potential in the mid-to-long term would be identified. These may include metabolics, which examines the chemical changes in an organism generating energy or materials required for life processes, computational biology/bioinformatics, and biomedical lasers and optics.

Special attention should be paid to promoting the convergence of health care and biosciences with other areas including information technology, optics, robotics, and microelectronics to create personalized or "genomic" medicine.

Address the Complexity of the Bioscience Research and Industry Enterprise Through Cooperative Endeavors.

The bioscience sector stands out from other technology sectors in the close relationship that exists between the research and industry enterprise. Major new products and innovations in the biosciences are frequently related to basic research discoveries while in other technology sectors the links are less direct. As a result, bioscience companies seek close interactions with academic researchers. Major university and non-profit research institutions are not only the key to basic research discoveries that can generate product leads for bioscience companies, but more importantly create an environment in which bioscience companies can flourish.

Colorado has both a base of bioscience companies and leading research institutions, yet these research institutions are not closely tied to industry. In order to grow Colorado's bioscience sector, closer collaboration between industry and academic researchers will be required. To achieve such collaboration will require that industry develop a greater understanding of the mission of the research institutions and the incentives that drives behavior of researchers and faculty, and that the research institutions provide access and respond to industry and entrepreneurs.

Multi-disciplinary and cross-institutional linkages will also be required to develop the type of research excellence described above. For example, The University of Colorado Center for Pharmaceutical Biotechnology is linking CU Health Sciences Center Pharmacology with the Boulder-based disciplines of Pharmaceutical Sciences and Chemical and Biological Engineering. The Center is serving a coordinating role in a range of research areas and serves as a conduit for a

significant number of pharmaceutical and biotechnology company-funded projects. If Colorado is to develop a cluster in the pharmaceutical biotechnology area, the center will need to extend its interaction with Colorado State University and other state bioscience research establishments. Another example is the proposed Rocky Mountain Institute for Biosecurity Research at CSU that is integrating statewide and regional expertise in infectious diseases, plant and animal biological agents and atmospheric sciences under one umbrella organization to coordinate and plan projects to meet pressing needs.

Similarly research and education initiatives that provide essential multi-disciplinary programs that will bring critical support to the bioscience industry need to be supported through their early phases. A good example is the computational biology program, which is a collaborative effort among CU campuses and located at the Denver campus.

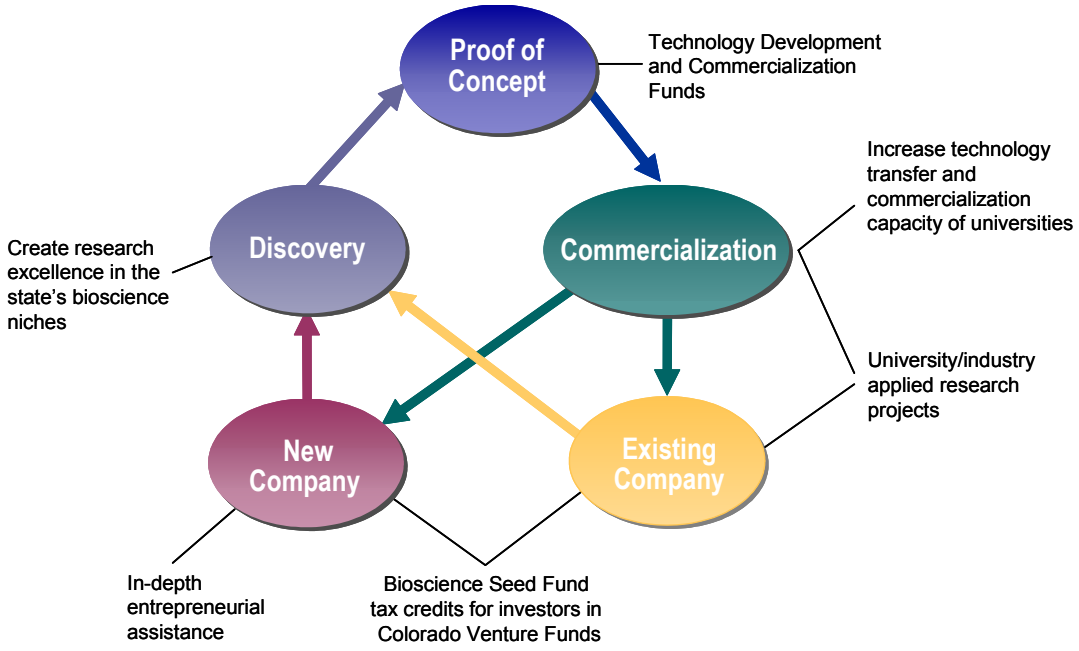
The Colorado Tobacco Research Program (CTRP) has been another successful multi-disciplinary and cross-institutional program. The CTRP supports comprehensive clinical, basic science, mental health, and evaluative research that serve Colorado's tobacco and substance abuse related health care needs. This approach serves as a good example of how to build relationships across disciplines and institutions to address complex issues and also bridge state policy priorities to the bioscience research and industry communities.

Lastly, the interrelationship of state policy and the biosciences will need to be recognized. The bioscience industry is a regulated industry and as such is impacted by federal and state health and regulatory policies. It will be important that state and local governments work cooperatively with the bioscience industry to ensure that policies are not enacted that would discourage the development of the biosciences in Colorado.

STRATEGIES AND ACTIONS

To move Colorado from having an emerging biosciences sector to the biosciences being a foundation of Colorado's economy will require an innovation climate in which research is advanced toward commercialization, there are proactive technology transfer interfaces, and new companies are created and emerging companies succeed and grow. Figure 26 presents the components of Colorado's bioscience plan that address each stage of the innovation cycle.

Figure 26: Overview of Colorado's Bioscience Plan.



Three strategies are proposed to grow Colorado's bioscience cluster.

- **Strategy One:** Create a business climate sensitive to and supportive of the needs and issues facing bioscience firms.
- **Strategy Two:** Grow the state's bioscience cluster by creating a bioscience entrepreneurial culture that turns research discoveries into new products and services and cutting edge firms and provides appropriate incentives to research institutions and industry.
- **Strategy Three:** Expand the research base and build research excellence in the state's bioscience niches.

Table 16 lists the proposed strategies and actions which are described below.

Table 16: Summary of Proposed Strategies and Actions

Strategy	Action
STRATEGY ONE: **Create a business climate sensitive to and supportive of the needs and issues facing bioscience firms.**	Enact a package of tax incentives to be triggered as the state's economy improves, to support the growth of Colorado's bioscience companies.
	Appoint a high-level Bioscience Advocate within state government.
	Review and ensure that state Medicaid policies relating to pharmaceuticals do not discourage building the bioscience industry in Colorado.
	Strengthen the voice of the bioscience industry in Colorado by forming a unified Bioscience Industry Association.
	Create a focus on the biosciences within the Governor's Office of Economic Development and International Trade.
	Develop and implement an industry-led, comprehensive communications strategy to educate and inform citizenry, elected officials, the nation and world about Colorado biosciences.
	Use the Colorado Institute of Technology to work with industry to identify and address emerging bioscience workforce needs at all levels.
STRATEGY TWO **Grow the state's bioscience cluster by creating a bioscience entrepreneurial culture that turns research discoveries into new products and services and cutting edge firms and provides appropriate incentives to research institutions and industry.**	Provide comprehensive in-depth entrepreneurial assistance to bioscience entrepreneurs and companies.
	Create a privately managed Colorado Bioscience Seed Fund and encourage a bioscience focus for angel investor networks.
	Enact legislation that would use state tax credits to guarantee investments in a "fund of funds" that would invest in private venture capital companies willing to invest in Colorado companies.
	Undertake activities that celebrate successful bioscience role models.
	Explore opportunities to establish plant-and animal-based pharmaceutical and nutraceuticals production within Colorado.
	Continue to build and strengthen technology transfer/commercialization capacity of universities.
	Create Technology Development Funds to support proof of concept and other commercialization activities.
STRATEGY THREE Expand the research base and build research excellence in the state's bioscience niches.	Complete full physical development of UCHSC/UCH Fitzsimons Campus to help anchor Colorado's bioscience research base for the future.
	Encourage collaborative partnerships between academic researchers and industry by providing funding for collaborative university/industry applied research projects, streamlining industry contracting, and designating an industry liaison.
	Identify opportunities and compete for national and federal institutes and centers of excellence in Colorado's bioscience niche areas.
	Develop a pilot program of product development and technical assistance support for the medical device, advanced manufacturing and bioagriculture development industries.

Strategy One: Create a business climate sensitive to and supportive of the needs and issues facing bioscience firms.

Action One: Enact a package of tax incentives, to be triggered as the state's economy improves, to support the growth of Colorado's bioscience companies.

Tax policies signal how states and localities prioritize their economic development efforts. Many states seeking to advance their bioscience industries are using their tax structures strategically to encourage private investment in bioscience firms, to ease the tax burdens on such firms, and/or to even the playing field between bioscience companies and traditional industries.

Traditional tax incentives put in place to encourage the establishment and growth of companies—tax credits for job creation and investment—generally do not benefit young bioscience companies due to the lengthy development process required to bring new bioscience paroducts to the market. In their early years, bioscience companies generally do not have profits, and therefore tax liabilities, that can be offset by tax credits.

In 1999, Colorado enacted legislation that allows qualified taxpayers to obtain a refund for Colorado sales and use taxes paid on purchases of personal property used directly and predominantly in R&D of biotechnology. It is recommended that Colorado develop a legislative package of additional tax incentives to encourage the growth of emerging bioscience companies that would be triggered as the state's economy improves. Consideration should be given to:

- ***Allowing biotechnology companies to sell unused Net Operating Loss (NOL) carryover to another tax payer***. Hawaii is an example of a state that allows high-technology businesses to sell its unused NOL to another taxpayer.
- ***Allowing bioscience companies with unused amounts of research and development tax credits that cannot be applied in the credit's tax year to transfer those credits for use by other corporation business taxpayers in the state***. Consideration could also be made to making R&D tax credits refundable. Examples of states that allow this are: New Jersey, which allows biotechnology companies with unused R&D tax credits to surrender those benefits to another corporation and Connecticut, which permits businesses with less than $70 million in gross sales to exchange unused R&D tax credits with the state for a cash payment equal to 65 percent of the value of the credit.

Action Two: Appoint a high-level Bioscience Advocate within state government.

Colorado is fortunate in that it has multiple organizations that are seeking to promote the development of the state's bioscience cluster. There is, however, no single point of contact that speaks for, or represents, the entire spectrum of bioscience interests. Nor is there a point of contact in state government for the bioscience industry. It is recommended that Governor Owens appoint a Bioscience Advocate, similar to the Aerospace Advocate, to be housed within the Governor's Office of Innovation and Technology. The appointment of a Bioscience Advocate will demonstrate the state's commitment to developing and supporting Colorado's bioscience sector. The Advocate will work closely with the bioscience sector, including both industry and academia, to identify needs and develop proposals to address those needs. The Bioscience Advocate will be

responsible for coordinating implementation of the Colorado Bioscience Plan and tracking progress.

Action Three: Review and ensure that state Medicaid policies relating to pharmaceuticals do not discourage building the bioscience industry in Colorado.

While many states are investing in initiatives designed to grow their bioscience sector, states are also passing legislation to limit the cost of prescription drugs or place limits on the use of certain drugs by Medicaid patients. Such policies can have an adverse impact on the very bioscience companies that these states are seeking to develop. Colorado should review the state's Medicaid policies relating to pharmaceuticals to ensure that these policies do not inadvertently discourage the building of the bioscience industry in the state.

Action Four: Strengthen the voice of the bioscience industry in Colorado by forming a unified Bioscience Industry Association.

Technology regions across the country have found it extremely important to have membership-driven networking and advocacy organizations that work within an industry or technology sector to address common needs and problems and to build image and awareness of the industry and related assets. Colorado has two organizations, the Colorado Biotechnology Association and the Colorado Medical Device Association, that represent various components of the bioscience industry. In addition, there are several other organizations, including the Colorado Alliance for Bioengineering, that undertake similar activities such as holding networking events and seeking to promote partnerships between bioscience companies and Colorado universities. The ability of each of these organizations to advocate on behalf of the bioscience sector and to facilitate the intensive networking required to support the growth of the biosciences is constrained by resources. ***A single, unified Colorado Bioscience Association should be established***. The Association should:

- Serve as a clearinghouse for information on the biosciences in Colorado. The association can provide a forum for bioscience companies and academic research institutions to exchange information on issues related to the biosciences and maintain data on Colorado's bioscience industry cluster.
- Advocate on behalf of the biosciences, identifying needs and developing proposals for policies and programs to address these needs.
- Act as a matchmaker and networker—the association can help connect groups and organizations and make them aware of opportunities. It can hold various events to bring higher education and industry representatives together to learn about trends and developments.
- Promote the image of Colorado as a center of the biosciences. The industry association can help publicize, inform, and educate the public through the media and through the events and programs it sponsors about the biosciences and its contribution to the Colorado economy.

The economic development community should work with the bioscience industry association in accomplishing these goals.

Action Five: Create a focus on the biosciences within the Governor's Office of Economic Development and International Trade.

The Governor's Office of Economic Development and International Trade markets Colorado for business and tourism development and assists companies interested in relocating to or expanding in Colorado. The state has few of the economic development incentive programs that other states use to assist companies directly, with the exception of a job training program that assists companies with customized job training. It is recommended that the state of Colorado undertake a business development effort focused on marketing the bioscience assets of the state and assisting bioscience companies wishing to locate in Colorado. Specific initiatives could include:

- Creating a state-level bioscience marketing team to coordinate participation in industry trade shows, developing lead generation efforts, and responding to inquiries from bioscience companies interested in locating in Colorado.
- Establishing an integrated, statewide, one-stop bioscience company response team that will ensure quick turnaround on permitting, deal packaging, research partners, and other needs of bioscience companies.
- Undertaking trade missions focused on domestic and foreign markets that provide opportunities for the biosciences.

Action Six: Develop and implement an industry-led, comprehensive communications strategy to educate and inform citizenry, elected officials, the nation, and the world about Colorado's biosciences.

For this bioscience plan to be successfully achieved, various groups and organizations across the state must come together to support its implementation. But, to do this is not easy or simple. The stakeholders will need to be committed to this effort for the long term; states do not build bioscience clusters overnight. And it will require a considerable degree of collaboration and connectivity among the various entities willing to work over many years for the common good of the state.

It is proposed that an industry-led campaign be undertaken to build awareness among state policymakers, business and community leaders, and the state's citizenry of the strengths of Colorado in the biosciences and the benefits to be derived from developing the state's bioscience sector. The bioscience industry association needs to assume a leadership role in accomplishing these goals. Specific actions that should be taken include:

- Engaging in ongoing, continuous dialogue with legislators and opinion makers on the importance of the biosciences and its contribution to Colorado's economy.
- Holding an Annual Bioscience Summit as part of an existing bioscience state event, such as BioWest.
- Organizing delegations to represent Colorado at national conferences, such as BIO.
- Undertaking public outreach and educational activities.

Action Seven: The Colorado Institute of Technology should work with industry to identify and address emerging bioscience workforce and education needs at all levels.

Existing Colorado bioscience companies indicated in interviews that they are generally able to find workers with the skills they need, although in some cases they must go out of state to recruit senior employees with experience in the biosciences. Some companies indicated that they had difficulty filling some positions such as medical technicians. While workforce does not appear to be a limiting factor at the moment, over time as the bioscience sector grows, there will be need for an increasing number of bioscience workers. Colorado is fortunate to have a highly educated population and an available workforce and educational institutions that will be able to provide the training needed to prepare people to become bioscience workers. The challenge will be to identify skill needs, to develop appropriate curricula, and to establish and fund programs for workers in this rapidly changing field. CIT should consider initiating a workforce survey to be conducted with support from the Bioscience Industry Association of the state's bioscience companies to assess demand for various skills, positions, and careers and then work with education and workforce providers to meet the needs identified. The text box below describes two programs created to meet the need for bioscience workers in Maryland.

In addition to ensuring that current and near term workforce needs are addressed, emphasis must be placed on working with industry and the state's research institutions to identify the degrees, programs, and courses that will be needed to position Colorado to grow the state's bioscience

BioTechnical Institute of Maryland

The BioTechnical Institute was created in 1998 to address the growing need for qualified and specially trained lab technicians in Maryland's rapidly expanding biotechnology industry. It does so with a variety of programs designed to increase the state's pool of credentialed bioscience and pharmaceutical technicians. It offers:

- Customized training for specific laboratory skills
- Laboratory accreditation courses (including GMP, GLP, and Safely)
- Curriculum design in coordination with bioscience firms and state universities and colleges to provide continuing education and skill validations
- Customized applicant pre-screening for bioscience firms.

The training and accreditation programs are fee of charge to participants who quality based on high school (or GED) record and aptitude assessments. The BioTechical Institute, organized as a not-for-profit corporation, is supported by the Abell Foundation, MDBIO (a private nonprofit corporation that seeks to advance the commercial development of bioscience in Maryland), Maryland state and local agencies, and the bioscience community.

Maryland-Johns Hopkins University: Master of Science in Biotechnology

The Johns Hopkins University offers a master of science in biotechnology as a part-time graduate program designed for professionals already working in the field, as well as for engineers, educators, scientists, and lawyers wishing to gain formal knowledge in biotechnology. The program includes 10 courses, and prerequisites include both an undergraduate degree in the natural sciences or engineering, or two semesters of college chemistry and two semesters of organic chemistry. Concentrations in bioinformatics and biotechnology enterprise are currently offered.

A certificate in biotechnology enterprise is available for those desiring a deeper understanding of the business aspects of biotechnology without completing an entire master's degree program—the certificate requires six courses.

niches. Increasingly interdisciplinary and multi institutional programs are required to educate, train, and graduate the future bioscience workforce. Those universities that are quickest to incorporate the results of technological advancements into their curriculum will have a lead in producing the talent needed by bioscience firms, particularly in multi-disciplinary fields that support Colorado's' bioscience competencies.

Colorado's research institutions have begun initiatives, such as the CU Center for Computational Biology, to address some of these needs already. The Center has launched certificate, master's, and PhD programs in computational biology, bioinformatics, and computer sciences. For Colorado to fully leverage its areas of key bioscience research strengths, enhanced capabilities in not only computation biology but in other areas such as bioengineering will be needed.

CIT serves as the central strategic planning entity that is charged with analysis assessing industry needs and higher educational institutions' capacity to respond. It is proposed that CIT work with Colorado's research institutions and industry to identify the degrees, program and courses that will be required to advance this bioscience plan and ensure that funding is available to establish and grow programs like the Center for Computational Biology. The technology platforms that offer the greatest opportunities for growing Colorado's bioscience sector and the programs and educational offerings required to support their development are identified in the core competency report prepared as part of the development of this plan.

Lastly, addressing the bioscience pipeline of future workers also is critical. A focus is required both on K–12 education and on technician-level education in community colleges, two areas from which the bioscience industry traditionally has not drawn its workforce but likely will in the future. CIT should work with the bioscience industry association to identify and address needs for K–12 and technician level education.

Strategy Two: Grow the state's bioscience cluster by creating a bioscience entrepreneurial culture that turns research discoveries into new products and services and cutting edge firms and provides appropriate incentives to research institutions and industry.

Action One: Provide comprehensive in-depth entrepreneurial assistance to bioscience entrepreneurs and companies.

One of the goals of Colorado's Bioscience Plan is to grow a critical mass of bioscience companies by encouraging new firm creation. This will require encouraging entrepreneurs and providing support to new start-up companies. Start-up and emerging technology companies need access to professional expertise, assistance in conducting market research and developing marketing strategies, and help in determining economic feasibility. They also need access to quality facilities with specialized equipment and laboratories, the ability to recruit key personnel, a support infrastructure familiar with technology businesses, and access to small amounts of preseed capital.

States and regions have begun to focus on ways to help entrepreneurs and companies to commercialize new technologies. These programs help entrepreneurs and companies in

transforming ideas or innovations into products ready for manufacture, marketing, and distribution. Several states including Florida, Kansas, and Oklahoma have created dedicated centers that offer a full range of commercialization support services. A few states have developed programs specifically targeted to bioscience companies. MdBio, a private nonprofit corporation originally created by the State of Maryland, awards funding to bioscience companies for product development and manufacturing, assists bioscience firms with marketing and regulatory issues, and provides financing for management of strategic planning.

Colorado has a number of organizations, including industry associations, incubators, the Colorado Bioscience Park Aurora, local economic development organizations, and university technology transfer offices, that provide some level of support to entrepreneurs and new start-up companies. These organizations should work jointly to create more in-depth programs for entrepreneurship education, and provide training, coaching and mentoring specifically targeted to bioscience companies. Services to be provided through these programs could include technology and market assessments, providing assistance in applying for Small Business Innovation Research (SBIR) and other grant programs, help in developing a business plan, and help in identifying and accessing sources of capital. The universities' business schools should be further engaged to assist in providing assistance to entrepreneurs and faculty seeking to commercialize research findings and/or interested in starting new ventures.

Action Two: Create a Colorado Bioscience Seed Fund and encourage the formation of bioscience angel capital networks.

A bioscience pre-seed/seed fund would provide post-angel but pre-venture financing so desperately needed by bioscience entrepreneurs. This stage of funding, which usually requires $250,000 to $2 million in individual investments, constitutes a critical private sector market gap for investment dollars as this size investment is usually too small for larger venture funds to consider. If Colorado can address this market gap, which is not unique to Colorado, the state will be better positioned to build a critical mass of bioscience firms.

Types of Capital Needed by Bioscience Firms

- **Commercialization funding**, which can be used to assess and undertake a review of the commercial potential of completed R&D.
- **Pre-seed and seed funding**, i.e., financing to support very early stage start-up companies.
- **Venture financing**, which is the capital needed prior to initial public offering. Given the long time frame required for the regulatory review process, bioscience firms will often require multiple rounds of venture financing.

Having a locally-managed, indigenous pre-seed/seed fund dedicated to the biosciences is absolutely essential for building the pipeline of firms which, as they gain experience and need additional funds to expand, become candidates for "major league" funding from larger, more diversified venture funds both in the region and from outside the region. The presence of a strong local bioscience investment fund is needed to attract outside regional and national funds to invest in Colorado.

Recognizing that building a critical mass of bioscience-related firms is unlikely without pre-seed and seed stage financing, many states and regions have developed programs to increase the availability of early-stage capital. States and regions have taken a variety of approaches including capitalizing funds that make direct investments in companies, investing in privately managed

venture funds, investing pension funds in venture capital, and using tax incentives to encourage investment in venture capital. In some cases, universities and foundations are investing a portion of their endowments in seed and pre-seed funding for bioscience companies. Twenty-eight states have one or more publicly-supported seed or venture funds that can invest in bioscience-related companies. Five states have publicly-supported seed and venture funds that invest exclusively in bioscience-related companies.

The North Carolina Bioscience Investment Fund, for example, was created with a $10 million appropriation from the North Carolina General Assembly in 1997. The fund, which has reached $25 million with the help of outside investors, has made four investments to date. In St. Louis, the Danforth Foundation, Washington University, and others have committed $150 million to invest in a series of bioscience venture funds, one of which will be a pre-seed/seed fund.

While Colorado companies in general have a good track record in terms of attracting venture capital, and Colorado bioscience firms have been successful in attracting outside later stage venture capital investment, there is a lack of very early stage seed and pre-seed capital for entrepreneurs and start-up bioscience companies. To address this need, the creation of a Colorado Bioscience Seed Fund is proposed. It is proposed that the fund, which would make investments in the range of $150,000 to $2 million, be privately managed. Potential sources of capital are private investors, university foundations, and state pension funds. The Fund would target itself to raise $35–$70 million for its initial capitalization. To address the need for even earlier, smaller levels of investment, the creation of bioscience angel capital networks should be encouraged.

Oklahoma Capital Investment Board

In 1992, Oklahoma created the Oklahoma Capital Investment Board (OCIB) to encourage equity and near-equity investments in private venture capital partnerships. The capital OCIB invests comes from institutional lenders and investors through the Oklahoma Capital Formation Corporation. The principal and interest on OCIB's borrowed funds are guaranteed if necessary by $50 million in tax credits with limits of $10 million of tax credits per year. State tax credits will be used only in the case that investment returns are insufficient to meet OCIB's guarantee commitments. Since its inception, OCIB has invested in eight private limited partnerships investing a total of $26 million. These funds have drawn down $18 million and invested (including co-investors) $66 million in 11 Oklahoma companies. The annual rate of return since inception has been 29.6 percent.

Action Three: Enact legislation that would use state tax credits to guarantee investments in a fund of funds that would invest in private venture capital companies willing to invest in Colorado companies.

Although some Colorado bioscience companies have been successful in obtaining venture capital, the majority of this capital has come from out of state funding sources. Over the long term, it will be important for Colorado to develop additional locally-based venture funds willing to invest in bioscience companies. It is proposed that Colorado enact legislation authorizing creation of a "fund of funds" that will invest in private venture capital funds that commit to investing in Colorado. Money for the fund of funds would come from the sale of stock to institutional investors such as banks and insurance companies, with the preferred stock having guaranteed dividend and redemption features. Tax credits would be used to collateralize the guarantees. Therefore, the credits would be used only if the cash flow from the fund of funds is insufficient to meet the obligations granted in the preferred stock. This proposed program would be similar to one that has been in place in Oklahoma since 1992 (see text box). Legislation for similar programs has been enacted in Iowa and Utah. One advantage of this approach is that the fund of

funds can direct investments to venture capital funds that invest in particular types of companies, such as bioscience companies.

In addition, it is proposed that legislation be introduced to provide state tax credits to individuals that invest in Colorado based bioscience-focused seed and later stage venture funds. In light of the state's current fiscal situation, the tax credit would be triggered at a predetermined point as the state's fiscal situation improves.

Action Four: Undertake activities that recognize successful bioscience role models.

One lesson from successful bioscience regions is that role models and entrepreneurial success stories are key parts of winning efforts to build entrepreneurial cultures. If Colorado wants to develop its bioscience cluster by growing its own bioscience companies, it will be important to convey to its citizens the opportunities presented by the biosciences and the success that has been and can be achieved by bioscience entrepreneurs. Colorado has a number of industry association and development organizations that seek to promote and build awareness of the biosciences in Colorado. The Colorado Biotechnology Association, Colorado Medical Device Association, Colorado Venture Centers and the Fitzsimons Redevelopment Authority, for example, hold monthly BioBreakfasts that provide opportunities to showcase bioscience companies. In October 2002, the first BioWest conference was held, which also provided an opportunity to highlight Colorado bioscience company success stories. These efforts should be continued and expanded. It is also proposed that a **Colorado Bioscience Entrepreneur of the Year Award** be established to reward and encourage successful bioscience entrepreneurs who will become the roles models for the next generation. A Colorado Bioscience Entrepreneur of the Year award will also promote the importance of the biosciences to Colorado's economy.

Action Five: Explore opportunities to establish plant and animal-based pharmaceutical and nutraceutical production within Colorado.

Colorado has been identified as a target market for agricultural-biotechnology for the production and processing of transgenic crops genetically engineered to produce pharmaceuticals and nutraceuticals. Recent advances in technology that enables genes for specific drugs to be inserted into major agricultural crops opens the possibility for revolutionary change in pharmaceutical and specialty chemical production. Using plants to produce drugs offers the possibility of greatly reducing the cost of transgenic drugs. Despite the opportunities this poses, there are also significant production related issues that arise with the movement of the production of active pharmaceuticals from a carefully controlled

Boston University's Community Technology Fund

The Community Technology Fund (CTF) is Boston University's (BU) name for its combined licensing office, commercialization function, and direct-investment fund. A separate unit of CTF, called "New Ventures," is responsible for developing new start-up companies based on BU technologies.

New Ventures makes "technology development awards" that are designed to "bridge the gap between government funded basic science and the more developed technologies that are of interest to commercial entities." The grants, which range from $20,000 to $50,000 but can be up to $100,000 under special circumstances, can be used to finance commercialization research or reduction to practice. Projects are selected based upon commercialization potential and the feasibility that the award will increase the value of a technology or the likelihood that it will be commercialized. The awards are not repayable.

environment to an uncontrolled outdoor environment. A number of communities in Colorado are already investigating opportunities for plant and animal pharmaceutical and nutraceuticals production. Elbert County, for example, has produced an Opportunity Assessment Plan and Adams County is also pursuing a similar initiative. It is recommended that Colorado move quickly to assess opportunities and develop an action plan to position Colorado to take advantage of this emerging bioeconomy.

Action Six: Continue to build and strengthen technology transfer/commercialization capacity of universities.

It is generally acknowledged that in the past, Colorado's universities have not emphasized technology transfer and commercialization. Despite this fact, a number of Colorado's successful bioscience companies have been founded by faculty and researchers from the universities. But during the last two years, the Colorado School of Mines, Colorado State University and the University of Colorado have each strengthened their commitment to technology transfer. In 2002, the University of Colorado system developed its first ever Strategic Plan for Technology Transfer, which sets a goal of being recognized as the best technology transfer office among public universities by 2010. The Colorado State University Research Foundation is implementing a Strategic Plan for Technology Transfer that was adopted in 2000. The universities should continue to emphasize the importance of commercializing research findings and provide the necessary support needed to operate effective technology transfer operations.

Action Seven: Create Technology Development Funds to support proof of concept and other commercialization activities.

Colorado has a strong base in basic research and its research institutions are making important strides to upgrade their technology transfer and commercialization activities. Nevertheless, a definite gap was identified in the tools available to encourage technology transfer and commercialization. Presently, there are no sources of funding for the follow-on activities needed to determine commercial potential, to identify potential licensees, or to determine whether there is a basis for forming a new firm around a technology.

A number of universities, such as Purdue University and Boston University, have established or are considering establishing technology development and commercialization funds. Numerous medical schools and centers also have established a variety of such funds, including May, Cleveland Clinic, Children's Hospital Boston, and Baylor. The adjoining text box describes the technology commercialization component of Boston University's Community Technology Fund.

Boston University's Community Technology Fund

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It is recommended that similar Technology Development Funds be established within each Colorado research institution that would provide financial support to ascertain the commercial potential of research findings and to move research toward commercial applications. The fund would provide funding in the range of $25,000 to $100,000 to undertake due diligence to determine commercial potential. This level of funding is needed to bridge the gap between basic science conducted at Colorado's research institutions and the development of technologies with commercial potential. The fund would make awards to be used to increase the value of a technology and to develop it to the point at which its commercial potential has been demonstrated. Awards could be used to develop a prototype or conduct further research that helps determine market value. The funds could seek contributions from alumni, foundations and high net worth individuals.

Strategy Three: Expand the research base and build research excellence in the state's bioscience niches.

Action One: Complete full physical development of UCHSC/UCH Fitzsimons Campus to help anchor Colorado's bioscience research base for the future.

The State of Colorado and the University of Colorado have committed to relocating UCHSC and UCH to a state of the art medical campus at Fitzsimons. The Children's Hospital is also relocating to the campus from its current location in Denver. The campus on which the University and hospitals are located is linked to the 160-acre Colorado Bioscience Research Park Aurora, which will house university-affiliated and emerging bioscience companies. The Fitzsimons site provides the opportunity to create an interactive community of bioscience research, teaching and patient care.

"There is great anticipation of an influx of positive economic growth...The combination of UCHSC/UCH and a huge bioscience research park will bring industry to the area. It will be a transfer between the basic sciences and the practical world."
James H. Shore, MD, Chancellor, University of Colorado Health Sciences Center

The initial phase of the move of UCHSC and UCH to Fitzsimons is estimated to cost $1.3 billion, which will result in an increase from 2.7 million gross square feet on 46 acres at the current location to 3.4 million gross square feet on 217 acres at the new location. Another 1.5 million gross square feet of space, mostly for research is slated for construction following the initial transition period.[30] Completion of the entire Fitzsimons building program will require a total capital investment of nearly $4 billion.

The university has proposed that the state issue Certificates of Participation (COP) to fund the completion of its portion of the Fitzsimons academic development, which totals $202 million.[31] The COP would be issued for $202 million over 25 years, requiring a $15.1 million annual contribution from the state. Funding for the $15.1 million would come from a variety of sources. Legislation to authorize the COP for Fitzsimons is currently under consideration by the Colorado

[30] http://www.uchsc.edu/fitzsimons/
[31] Under this proposal, the state would enter into lease-purchase agreements to build capital facilities. If approved, the state's annual lease payments will be marketed to investors as certificates of participation. A "certificate" refers to an investor's proportionate interest in the state's lease payments.

legislature. Enactment of this legislation will help move forward the development of the Fitzsimons campus, a key component in advancing the development of Colorado's bioscience cluster.

While the location of the UCHSC/UCH campus at Fitzsimons is a key anchor, Colorado should work with its Congressional delegation to identify opportunities for federally supported facilities to locate at Fitzsimons. One facility already identified is the VA Medical Center. The relocation of the VA Medical Center to Fitzsimons should continue to be pursued as it would provide another important anchor for the campus and would be a key component in the network of institutions providing patient care, biomedical research, education and biotechnology R&D at the Fitzsimons site.

BioSTAR

An excellent example of an industry/university matching grant program in the biosciences is the University of California's Biotechnology Strategic Alliances in Research (BioSTAR) program. Established in 1996, this mechanism links life science companies with researchers in their field through a modest matching grant. BioSTAR involves a highly competitive process in which research proposals are peer reviewed and companies must provide at least half the cost of the project. Since its inception, BioSTAR has fostered linkages between many of California's small, emerging, life science companies and the University of California campuses, providing a highly valuable competitive edge to its emerging, small, life science companies.

Action Two: Encourage collaborative partnerships between academic researchers and industry by providing funding for collaborative university/industry applied research projects, streamlining industry contracting, and designating an industry liaison.

As discussed above, it is commonly acknowledged that Colorado's universities do not have a strong history of collaborating and connecting with industry. For Colorado to become a leading bioscience center, it needs to build sustained relationships between its bioscience companies and the state's research institutions. One way to accomplish this is to provide funding for collaborative university/industry applied research projects. Such projects help build relationships between researchers and companies and provide support for activities that help to move technology to the point where private investment capital can be obtained.

At least a dozen states have matching grant programs that provide an incentive for firms to support research projects at local research institutions. One such program is Utah's Centers of Excellence Program. The Utah program is somewhat misnamed as it is really a project grant program, not a centers program. Nevertheless, it represents an example of a challenge grant program intended to create enduring academic/industrial partnerships that lead to ongoing support and commercialization of intellectual property within the state. Budgeted at about $2 million a year, the Centers program supports about 15 projects at any one time, with allocations up to a maximum of $200,000 per project. The program supports faculty at Utah universities, helping them to advance the research program in a way that attracts interested industrial partners from within the state. State funding must be matched by industrial partners. Since 1986, a total of nearly 80 projects were funded at a cumulative investment of $832 million, matched 10:1 by funds from industrial partners. The Center program is credited with the creation of 150 new companies and 204 license agreements. Another program designed to promote industry/university partnerships that is focused exclusively on the biosciences is California's BioStar program, which is described in the text box.

National best practice suggests that matching grant programs are the most effective method when compared with other types of university/industry partnerships that exist to promote technology commercialization. Another approach to providing funding for higher education/industry partnerships is to use tax credits to build stronger and more sustained relationships between state industries and research institutions. It is proposed that Colorado create a project matching program or R&D voucher program that would provide funding for industry research projects conducted by Colorado research institutions. It is proposed that funding be provided in the range of $125,000–$250,000. The industry partner must match the state funds on a 3:1 basis. The annual budget for this program would be approximately $2–$2.5 million annually.

Another action that the universities can take to encourage more collaborative research with industry is to streamline industry contracting procedures and make them more user friendly. Lastly, there is a need to continue dialogues to build greater understanding on the part of faculty of industry needs and requirements and on the part of industry of university missions and requirements. The Colorado Biotechnology Association should take the lead in helping industry to learn how to access and partner with universities. For their part, each of the research institutions needs to commit to being responsive to industry requests. It is recommended that each research institution designate an industry liaison to serve as an initial point of contact for industry wishing to find industry researchers with which to interact.

Action Three: Identify opportunities and compete for national and federal institutes and centers of excellence in bioscience niche areas.

Increasingly states, through their public and private representatives, have been working closely with their Congressional Delegations to ensure federal investments are made that help create the research and research infrastructure anchors that help build bioscience economies. As noted in the description of best practices, one key lesson for state and regions building a bioscience economy is the importance of federal funds for federally-designated centers and institutes, whether the funding comes in the form of operating or capital funds. Almost every major mature bioscience region or state in the U.S. has one or more federal anchors that have contributed to building its bioscience base, e.g., NIEHS in Research Triangle Park, Lincoln and Draper Labs in Boston, and NIH in Maryland. Discretionary federal funding unfettered by federal mission also plays a role in enabling exploratory research to be undertaken that may lead many years later to applications in various bioscience areas.

In order to develop research excellence in selected areas, Colorado's research institutions will have to come together to collaboratively pursue opportunities for federal and other sources of research funding. A good example of where this has happened recently is the proposal that has been submitted to the National Institute of Allergy and Infectious Diseases for a regional center of excellence in bioterrorism and emerging infectious diseases by a coalition of regional research institutions led by CSU and the CDC laboratory in Fort Collins.

Action Four: Develop a pilot program of product development and technical assistance support for the medical device, advanced manufacturing and bioagriculture development industries.

One potential way to bring firms, particularly small and medium sized device firms, into closer contact with research organizations is by forming a pilot demonstration program whereby a product development/technical assistance center can be established at one of the University campuses in Colorado. Alternatively, the bioprocessing scale up facility at CSU could be used to house such a center. This effort should be undertaken as a pilot project to determine whether such a center would be effective in creating relationships and communications between industry and academe. If successful, additional pilot centers serving other industries can be considered or the pilot program could be expanded and made permanent. New York's Energy and Environmental Technology Applications Center provides these types of services to encourage the use of nontechnologies to develop energy and environmental products and services. See text box.

New York's Energy and Environmental Technology Applications Center

In 1998, New York established the Energy and Environmental Technology Application Center (E2TAC) at Albany Nano. The Center seeks to apply emerging nanotechnologies to address technological issues affecting the development of energy and environmental-related applications. The Center helps companies to overcome technology, market and business development barriers by providing incubation, pilot prototyping and test bed integration support. The Center accomplishes this by supporting company specific projects as well as developing technology roadmaps and commercialization pathways. E2TAC plans to establish an alternate technology test farm that would have the unique resources needed to test energy technologies.

Implementation Plan

Colorado is well positioned to grow its bioscience cluster. But if Colorado is to succeed in capturing significant growth in this sector, it must act quickly as other states and regions are aggressively making investments to attract and grow their bioscience sectors. If Colorado is to achieve its vision for the biosciences, it must rapidly implement the strategies and actions in this plan.

This plan has been developed with the support of the State of Colorado, Colorado's bioscience industry, the state's research institutions, and economic development organizations. Each of these stakeholders has a role to play in implementing the plan. But it is also important that one entity take responsibility for coordinating the efforts of the various players and monitoring progress. It is recommended that the management team that developed the Plan and the state's Bioscience Advocate play this coordinating and monitoring role. It is further proposed that the bioscience industry, through the Bioscience Industry Association, take lead responsibility for implementing the Plan and leveraging other stakeholders to take responsibility for key elements of the plan.

In addition to the Colorado Bioscience Industry Association, key stakeholders responsible for implementing various actions include:

- Governor's Office of Economic Development and International Trade
- Colorado's research institutions, with leadership from the University of Colorado and Colorado State University
- Colorado's economic development organizations, with leadership from the Metro Denver Chamber of Commerce and other chambers and economic development organizations throughout the state
- Colorado Institute of Technology.

It is recommended that each of the stakeholders identify and commit to implementing the actions appropriate to their organization.

Priority Actions

In light of the economy and the current fiscal condition of the state, it is important to identify those actions that are likely to have a direct impact on the development of Colorado's bioscience sector. It is recommended that the following actions be undertaken immediately.

1. **Appoint a Bioscience Advocate within state government.** Input collected by Battelle through interviews with CEOs and bioscience entrepreneurs indicated that a commitment on the part of the state's public leaders to support the development of Colorado's bioscience sector could provide a significant boost for the industry and would play a role in encouraging firms to both locate in Colorado and remain in Colorado as they grow. It is proposed that the Governor appoint a Bioscience Advocate to be housed within the Governor's Office of Innovation and Technology. The Advocate will work closely with

the bioscience industry to address issues facing the industry and will also promote partnerships between industry and researchers, encourage the commercialization of bioscience discoveries and inventions, and facilitate policies and programs designed to support the start-up and growth of bioscience companies.

2. **Continue to build and strengthen technology transfer/commercialization capacity of universities, including creating technology development, proof of concept funds**. Colorado's research institutions have made a commitment to place greater emphasis on technology transfer and commercialization of research findings. These institutions must not only continue to provide support for these activities but must begin to develop the tools and mechanisms to facilitate commercialization. As a first step, it is proposed that the state's research institutions initiate the creation of technology development funds that will provide financial support for proof of concept and other commercialization activities. These funds would provide financial support in the range of $25,000 to $100,000 to undertake due diligence to determine commercial potential of research institution developed inventions. The individual institutions should seek contributions from alumni, foundations, and individuals for the funds.

3. **Complete development of UCHSC/UCH Fitzsimons Campus.** The University of Colorado and the State of Colorado have made a substantial investment to develop the UCHSC/UCH campus and the adjacent Bioscience Park at Fitzsimons. Over the long-term, this site presents the opportunity to develop into a significant hub of bioscience activity involving research and medical institutions and companies working side by side and in partnership. It is critical that the University and the State continue to provide the support needed to complete the development of the Fitzsimons campus. An initial step in this direction will be to approve the proposed Certificates of Participation that are under consideration by the state legislature.

4. **Strengthen the voice of the bioscience industry in Colorado by forming a unified Bioscience Industry Association.** This action plan was developed with the expectation that Colorado's bioscience industry, working in partnership with the state's research institutions and governments, will take the lead in implementing the action agenda to grow the state's bioscience sector. In order to accomplish this, Colorado needs a very active industry organization that can provide a focal point for the state's bioscience development efforts. A single bioscience industry organization should be established that will be responsible for networking academic, industry, and public and nonprofit groups and organizations, and encouraging cross-fertilization of ideas and opportunities.

5. **Create a privately managed Colorado Bioscience Seed Fund and encourage creation of bioscience focused angel investor networks**. Leading bioscience regions share one characteristic: they are home to a venture capital community that is both oriented toward early-stage financing and committed to local investment. Having local venture capital funds with experience investing in bioscience companies is critical. These regions also have networks of successful entrepreneurs who act as angel investors, willing to invest in very early stage start-up companies. It is generally agreed that, as in most states and regions, Colorado lacks early stage capital for bioscience entrepreneurs and companies. It is recommended that a privately managed Colorado Bioscience Seed Fund that would make investments in the range of $150,000–$2 million be created. Private investors,

university foundations and the state's public pension funds should be approach about investing in the Fund. To address the need for even earlier, smaller levels of investment, the creation of bioscience angel capital networks should be encouraged.

6. **Explore opportunities to establish plant-and animal-based pharmaceutical production within Colorado**. Battelle's research indicates that the Colorado bioscience environment is well positioned to assume leadership within the fast moving field of plant biotechnology. Indeed, a number of Colorado communities are already exploring possibilities for plant and animal pharmaceutical and nutraceuticals production. It is recommended that Colorado move quickly to assess opportunities and develop an action plan to position Colorado to take advantage of this emerging opportunity.
7. **Create a focus on the biosciences within the Governor's Office of Economic Development and International Trade**. Colorado's Office of Economic Development and International Trade works with companies expanding in or relocating to Colorado and helps existing companies with workforce, financing and other issues. In order to develop Colorado's bioscience sector, it is recommended that the Office create a state-level bioscience marketing team and establish an integrated, one-stop bioscience company response team that will ensure quick turnaround on permitting, deal packaging, research, partners and other needs of bioscience companies.
8. **Develop and implement an industry-led, comprehensive communications strategy.** A key element of implementing this action plan will be to educate and inform the state's leaders and citizenry about the biosciences and its contribution to Colorado's economy. A strategy should be developed and implemented to build local awareness of the strengths of Colorado in the biosciences and the benefits to be derived from developing the state's bioscience sector. The statewide bioscience industry association should take responsibility for keeping citizens informed about Colorado's bioscience efforts, relaying stories of success, and charting progress and results.

MEASURES OF SUCCESS

It is recommended that the following measures be used to gauge success and progress in implementing Colorado's bioscience plan.

- Increase in bioscience R&D funding at Colorado research institutions equal to or greater than the national average.
- Increase in industry funding of bioscience R&D at Colorado research institutions to the national average for industry funding as a percent of total R&D funding.
- At least $100 million in federal and other bioscience dollars attracted to Colorado for centers and national institutes by 2008.
- Increase commercialization of bioscience technology developed at Colorado research institutions as measured by number of new start-ups and number and value of licenses.
- Growth in state's bioscience economic base: number of firms, their employment, their concentration in the state relative to the nation, and birth and death rates of firms.

- Indigenous venture capital dollars invested in Colorado bioscience companies will reach $50 million by 2008.
- Implementation progress on the actions laid out in the plan of at least 70 percent with substantial action after three years, and 90 percent within five years.

Conclusion

Colorado is fortunate to possess strong assets in the biosciences that offer great potential for the state's economy. To date, the state's bioscience sector has developed largely by serendipity and if left alone would be likely continue to grow somewhat. But this sector has the potential to become a true driver of Colorado's economy.

Taking advantage of the opportunities provided by the biosciences in Colorado will require:

- Commitment and willingness to collaborate on the part of the public, private and academic communities.
- Achieving research excellence with national level focus in selected areas.
- Commitment on the part of Colorado's universities to a broad commercialization program to capitalize on technology transfer and entrepreneurial activities.
- Continued investment in bioscience infrastructure, including the completion of the Fitzsimons development.
- Commitment on the part of the State of Colorado to support the bioscience sector.

In the early years of the New Millennium, the biosciences have emerged as one of the most dynamic and growth-oriented sectors of the economy. Advances in the biosciences will likely revolutionize the economy of the coming decade, as telecommunications and computer technology did in the prior decade. Colorado has the opportunity to seize the opportunity presented by the biosciences and build an industry that will not only have economic development benefits but that can improve the health and well being of Colorado's citizens.

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Appendix A: Colorado Bioscience Research Strength Areas

Field	Pulmonlogy
Field Definition	The medical practice pertaining to the lungs and respiratory system.
Interview Identified Strengths	• National Jewish Medical & Research Center ranked the #1 respiratory hospital in U.S. five years in a row. University Hospital Denver ranked 7th in respiratory disorders. • Considerable depth in basic science research and in translational and clinical research. • Basic sciences focus (with multiple NIH grant awards) in: o Signal transduction o Structural biology o Cell biology o Oxidant biology • Translational/Clinical focus (again with multiple NIH grants) in: o Allergies o Asthma o Lung diseases (tuberculosis, chronic obstructive lung disease, cystic fibrosis, interstitial lung diseases) o Sleep o Occupational medicine • Interstitial Lung Disease Clinic considered the premier clinic for such disorders in the U.S. • Interviewees noted pulmonology at National Jewish/UC-HSC to also be strong in acute lung injury, emphysema, pulmonary hypertension and genomics. • The US-HSC Pulmonary Hypertension Center is investigating the relationship between collagen-vascular disorders and primary pulmonary hypertension. • Pediatric pulmonology is strong, with multiple NIH grants. • CSU is home to one of the world's leading researchers and research programs in tuberculosis. The university also has expertise in animal respiratory disorders, such as ovine progressive pneumonia. • Interviewees noted that there has not been much technology transfer based on pulmonology research and practice in Colorado.
Supporting Statistics	• NIH designates National Jewish as a Specialized Center for research in interstitial lung diseases • National Jewish has 103 faculty members, including 69 physicians/physician-scientists and 34 basic scientists • National Jewish receives $39 million in research funding, including 125 NIH awards • University of Colorado pulmonology is operated cooperatively with National Jewish. UC has 19 NIH awards in the related field of cardiovascular-pulmonary research and a further 35 NIH grants in pulmonary sciences and critical care medicine
Key Institutions	• National Jewish Medical and Research Center • University of Colorado Health Sciences Center • UC Children's Hospital and pediatrics department for pediatric pulmonology

Field	Immunology
Field Definition	The study of the immune system and the science concerned with the various phenomena of immunity, induced sensitivity and allergy. Includes mechanisms that control host-pathogen responses and auto-immunity.
Interview Identified Strengths	• National Jewish Medical and Research Center said to be the top private institution in the U.S. for research in immunology. • National Jewish operating strong basic science programs with significant NIH funding in: o B Cells and T Cells o Immunovirology o Immunodeficiency o Allergies • National Jewish clinical and research expertise specific to autoimmune diseases (including, for example, lupus, Kawasaki's disease, and vasculitic syndromes). • UC Health Sciences Center with research in autoimmune disorders and diseases, including HIV/AIDS and celiac disease. • Distinct links in Colorado between cancer research and immunologic expertise. • Type I diabetes expertise, within the Barbara Davis Center for Childhood Diabetes, focused on diabetes and auto-immune causal linkages. • Immunology expertise extended across to research in a broad number of medical research programs at UC-HSC including, for example: immunologic injury and cardiac health and rheumatology. • Colorado State University veterinary medicine and biomedical sciences also with a significant track record in NIH immunology grant awards, with a focus on animal vaccines and cancers. The Feline Leukemia vaccine was developed at Colorado State, and the University holds an NIH contract to provide the research community with virulent Mycobacterium tuberculosis and its various products. This contract includes the testing of candidate anti-tuberculosis vaccines. • CSU also has deep research experience in immune responses to mycobacterial diseases.
Supporting Statistics	• National Jewish has >25 NIH awards for research in or related to immunology • University of Colorado has 16 NIH grants in immunology and allergy/clinical immunology • The University of Colorado Health Sciences Center published 510 papers in immunology (with a 4.03 publications concentration ratio) and 230 papers in clinical immunology and infectious diseases (3.93 PCR) • The University of Colorado in Boulder published 527 papers in immunology (1.95 PCR) and 239 papers in clinical immunology and infectious diseases (1.91 PCR)
Key Institutions	• National Jewish Medical and Research Center • University of Colorado Health Sciences Center • University of Colorado - Boulder

Field	Infectious Diseases
Field Definition	• Includes acquired diseases caused by infectious agents such as viruses, bacteria, myco-bacteria and prions.
Interview Identified Strengths	• Colorado State University veterinary medicine program center of scholarly excellence in infectious diseases. Expertise in: o Vector borne diseases (mosquito-borne encephalitis, yellow fever, dengue, hantaviruses, parasitic diseases, and Lyme disease). 30 researchers operating within center. o Viral and retro-viral diseases o Bacterial and myco-bacterial diseases o Prion diseases • CSU also has strengths in plant pathogens (bacterial/fungal/insect). • Growing efforts at UC-Boulder in studying the microbial basis for disease, with strong connections to RNA analysis allowing for more fundamental and broad-based analysis into pathogens than typically found at other institutions. • National Jewish work with lung infectious diseases including myco-bacterial infections (e.g. tuberculosis). • CDC Division of Vector-borne Infectious Diseases operates research lab and Level-3 containment facilities at CSU Foothills Campus and the USDA operates the Arthropod-Borne Animal Diseases Research Laboratory 60-miles north in Laramie, Wyoming. In collaboration with CSU scientists the labs are marrying field investigations with population genetic and genomic approaches to understand transmission, persistence, emergence, and control of vector-borne pathogens. • University of Colorado Health Sciences Center has funded research in HIV/AIDS, including AIDS pathogenesis and cytokine biology. • Multi-institutional expertise in human, animal and plant infectious diseases being leveraged for biosecurity/bioterrorism applications. CSU has formed the Rocky Mountain Institute for Biosecurity Research protecting humans, animals and crops from biological, chemical and radiologic harm.
Supporting Statistics	• 38 NIH grants to University of Colorado Infectious Diseases Division • 8 NIH grants in pediatric infectious diseases • 29 NIH grants in microbiology to CSU, and 16 to UC-HSC • Ranked 10th in AIDS as a medical research specialty (U.S. News) • UC-HSC 230 papers (3.93 PCR) in clinical immunology and infectious diseases • UC-Boulder 239 papers (1.91 PCR) in clinical immunology and infectious diseases
Key Institutions	• Colorado State University • University of Colorado Health Sciences Center • University of Colorado-Boulder • National Jewish Medical and Research Center

Field	Pediatrics
Field Definition	A multidisciplinary field of medicine concerned with the care of young humans from birth through to the age of 18.
Interview Identified Strengths	• The pediatrics department at UC-HSC writes *Current Pediatric Diagnosis & Treatment*, a "bible" for family physicians and pediatricians. • The Pediatric General Clinical Research Center at The Children's Hospital is one of only nine exclusively pediatric research programs in the U.S. funded by the NIH. It receives $3.1 million annually in direct NIH funding and has more than 100 active research protocols. • Faculty in Perinatalogy said to be on the leading edge of research in maternal, placental and fetal physiology. Research primarily involves reproductive and developmental physiology and biochemistry. • The Pediatric Heart Lung Center (including pediatric pulmonology) is a research and clinical care program focused on developing approaches towards the investigation and treatment of severe cardiac and pulmonary disorders in children. • Deep expertise in child abuse at the Kempe Children's Center. • Considerable research into Down's syndrome contained within the Eleanor Roosevelt Institute. • Children's Hospital and the Department of Pediatrics at UC-HSC serve a seven state area for clinical care. • Expertise in abnormal child development at the Mental Retardation and Developmental Disabilities Research Center.
Supporting Statistics	• 139 NIH grants in pediatrics and pediatric related fields at the University of Colorado • $46 million in total 2001 research grants to UC-HSC Pediatrics, including more than $20 million in NIH funding • Children's Hospital Denver ranked 4th in the nation in the U.S. News Best Hospitals ranking system • Ranked in the Top 10 for NIH grants to pediatrics • Ranked 14th by U.S. News for pediatrics as a medical research specialty area • UC-HSC 239 papers (3.99 PCR) in Pediatrics • UC-Boulder 279 papers (1.94 PCR)
Key Institutions	• Children's Hospital Denver • University of Colorado Health Sciences Center • Denver Health Medical Center • National Jewish Medical and Research Center • Eleanor Roosevelt Institute

Field	Oncology
Field Definition	The study or science dealing with the physical, chemical and biologic properties and features of tumors including causation, pathogenesis and treatment.
Interview Identified Strengths	• Interviewees cited UC-HSC and associated cancer institutions having particular expertise in breast cancer, lung cancer, lymphoma, melanoma, prostate cancer and genital-urinary cancer. • Interviewees mentioned emerging strength in hematologic cancers. • The University of Colorado Cancer Center has multiple NIH funded grant recipients. Focus of research is on: o Cancer genetics o Cancer immunology and immunotherapy o Pediatric oncology o Developmental therapeutics o Carcinogenesis and chemo o Hormone related malignancies o Molecular and structural biology investigations o Tobacco related malignancies • The Cancer Center appears to be supported with a strong suite of core labs and resources and there will be a 274,000 gross square feet Cancer Research Tower constructed adjacent to the Biomedical research Tower at the new Fitzsimmons campus. • Colorado State University, within the vet school, has a strong focus on animal cancers and operates the Animal Cancer Center and Medical Oncology Research Lab. Research focus there is on: o Nutrition and cancer o Metalloproteinase blocking o Chemo o Immunity and cancer • There are working links between CSU and the UC-HSC in cancer focused on osteosarcoma and lymphoma (both of which effect humans, but are more common in animals). • CSU also maintains a Cancer Prevention Laboratory within Horticulture working on novel plant root extracts for chemoprevention, plant effects on reducing oxidative cellular damage, and plant phytochemicals with anti-cancer, anti-aging and anti-obesity activity.
Supporting Statistics	• UC Cancer Center shows 17 NIH research grants, while the UC-HSC records 18 NIH grants in medical oncology and 4 in pediatric oncology • University of Colorado blood and bone marrow transplant program has 5 NIH grants • University Hospital ranks 41st in cancer in the U.S. News Best Hospitals ranking system • UC-HSC 175 papers (2.22 PCR) in Oncology and 211 papers (3.93 PCR) in Oncogenesis and Cancer Research
Key Institutions	• University of Colorado Cancer Center • University of Colorado Health Sciences Center • Colorado State University Veterinary Medicine • National Jewish – for Lung Cancer and Malignant Mesothelioma

Field	Neurosciences
Field Definition	The discipline concerned with the development, structure, function, chemistry, pharmacology, clinical assessments, and pathology of the nervous system.
Interview Identified Strengths	• UC-HSC Department of Neurology said to be known internationally for research in viral and immunological disease of the nervous system. Unusually large cluster of individuals studying infectious disease in the human nervous system. 25+ MDs, PhDs, grad students and research assistants investigating: the molecular pathogenesis of herpes virus latency in the nervous system; the mechanism of virus-induced programmed cell death (apoptosis); neurotrophin development in the mammalian eye; mechanisms of neuronal inhibition, and the properties of synaptic connections between neurons in epileptic neural networks. • Many interviewees at UC-Boulder and UC-HSC cited neurosciences being broadly strong but not focused. The neuroscience community at UC-Boulder is made up of over 80 faculty and research associates rostered in 13 departments and institutes. Neuroscience activities on the campus are coordinated by the Center for Neuroscience and a new PhD program in neurosciences has recently been initiated that cuts across departments. • The Psychology Department at UC-Boulder has 50 PI's and there are good strengths said to be at the campus in behavior, neurobiology, neuropharmacology, computer sciences and molecular, cellular and developmental biology. • Work in the neurosciences at UC is highly interdisciplinary addressing cognitive disabilities, spinal cord injuries, trauma, Parkinson's disease and Alzheimer's disease. • Molecular and Cellular Integrated Neurosciences at CSU focuses on areas related to neuronal differentiation, degeneration and regeneration, ion channels and membrane physiology, synaptic mechanisms, neuronal circuitry and chronobiology, sensory biology, artificial neural networks, cognitive neuroscience and neurovirology.
Supporting Statistics	• 21 NIH grants at UC-HSC in Neurology • 38 NIH grants to Psychology at UC-Boulder • 13 NIH grants to CSU in anatomy and neurobiology • UC-HSC 524 papers (1.88 PCR in Neurosciences and Behavior and 124 papers (1.49 PCR) in Neurology • UC-Boulder 747 papers (1.25 PCR) in Neurosciences and Behavior
Key Institutions	• University of Colorado Health Sciences Center – Neurology • UC-Boulder multi-departmental via Center for Neuroscience • Colorado State University – Molecular and Cellular Integrated Neurosciences

Field	Pharmacology and Pharmaceutical Sciences
Field Definition	The science concerned with drugs, their sources, appearance, chemistry, actions and uses.
Interview Identified Strengths	• The University of Colorado is home to the Center for Pharmaceutical Biotechnology (CPB) – working on drug delivery, formulation, analytical methods and processing, with a particular focus on protein-based drugs and their stability. Convened under the UC School of Pharmacy (in cooperation with UC Chemical Engineering), the CPB is divided into three research cores: o Pharmaceutics, covering drug stability and drug delivery research o Molecular biology, where recombinant DNA technology is employed to identify new drug targets, synthesize macromolecular therapeutics, and understand the molecular basis of disease o Analytical chemistry, where new methods are developed to characterize macromolecular structure, in vivo drug concentrations, and drug purity • In a relatively short period of time the CPB has built relationships with most of the powerhouse companies in the biopharm sector, including for example: Amgen, Bayer, Eli Lilly, Genentech, Merck, Novo Nordisk and Zymgenentics. It has also generated a major spin-off company (RxKinetix). • UC Boulder also has a growing group of faculty focused on the synthesis of new chemical agents, with an emphasis on natural products and the development of innovative synthetic methods. • CSU runs the Colorado Bioprocessing Center (CBC) with the mission of strengthening the biotechnology industry in Colorado by providing expertise and facilities for the development of enabling technologies to improve biotechnology production processes and through education and training of students and employees of biotechnology companies. The CBC provides services for the development, optimization, and scale-up of production-worthy bioprocesses from fermentation and cell culture through product recovery and purification. • BioServe Space Technologies at UC provides services for facilitating space based research for biotech applications in agriculture, biomedicine and biotechnology. Industry work being performed for Amgen and Chiron Corporation.
Supporting Statistics	• 59 NIH grants to UC Pharmacology • 27 NIH grants to Pharmaceutical Sciences at UC • 9 NIH grants in Clinical Pharmacology/Toxicology • UC School of Pharmacy ranked 31st by U.S. News • UC-HSC 242 papers (1.58 PCR) in Pharmacology/Toxicology
Key Institutions	• University of Colorado – Boulder and HSC • Colorado State University

Field	Cardiology and Cardiovascular Systems
Field Definition	The branch of medicine dealing with the heart and blood vessels. Also includes the cardio-pulmonary field examining the heart and lungs as a system.
Interview Identified Strengths	• Interventional cardiology said in interviews to be strong at UC-HSC. Research in interventional cardiology has focused on using 3D imaging using a team of computer scientists and interventional cardiologists. Coronary arteries are displayed in 3-D and can be rotated to simulate any view. • The University of Colorado Health Sciences Center is said to be one of the leading academic heart failure facilities in the world providing investigational drug therapies and diagnostic techniques. Interviewees cited work in basic sciences related to immunological injury and heart attack risk. • The Temple Hoyne Buell Heart Center Laboratories (at UC) for Research in Molecular Cardiology are dedicated to the research of molecular and genetic research of Heart Failure. • The University of Colorado Cardiovascular Institute supervises work between research performed on the Boulder campus and at UC-HSC. • UC-HSC operates the Cardiovascular Pulmonary Research Laboratory which focuses on human adaptation to hypoxia, including high altitude pulmonary edema, pulmonary hypertension, acute lung injury, and ventilation control. • At CSU, researchers are investigating animal cardiovascular health and transplantation.
Supporting Statistics	• 39 NIH grants in cardiovascular and cardio-pulmonary research at UC-HSC • 2 NIH grants in the UC Heart Failure Program • UC-HSC 388 papers (2.63 PCR) in Cardiovascular and Respiratory Systems and 374 papers (2.77 PCR) in Cardiovascular and Hematology Research • UC-Boulder 410 papers (1.30 PCR) in Cardiovascular and Respiratory Systems and 402 papers (1.39 PCR) in Cardiovascular and Hematology Research
Key Institutions	• University of Colorado Health Sciences Center • University of Colorado - Boulder

Field	Molecular, Cellular and Developmental Biology
Field Definition	Note: There is overlap in science between these fields. **Molecular Biology** – The study of gene structure and function at the molecular level. **Cellular Biology** – The study of the cell as the basic structural, physiological, and reproductive unit of life **Developmental Biology** – the study of all aspects of biological development, from the genes and molecular events that control development, through to the structural changes that an organism undergoes as it develops.
Interview Identified Strengths	• 31 research faculty contained within Molecular Cellular and Developmental Biology at UC-Boulder with diverse research interests. The department brings a considerable emphasis on the development of techniques for measurement and analysis. o Historically, MCD has had close linkages with RNA analysis ongoing on campus, providing insights into the biological mechanisms of RNA. o Strong emphasis on neurobiology with close linkages to the Psychology department. o Highly regarded cell biology efforts involving strength of the 3D lab and basic biological sciences related to cell biology, including cell signaling, cell differentiation and cell death. o Emerging area of microbial pathogenesis, which began with examination of microbial life in extreme environments, but now is focused on microbial basis for human diseases. • Colorado State University interviewees noted strength of their own program in cell and molecular biology, with focus areas being: o Animal and plant reproduction and development o Cancer biology o Transcription and transcription regulation o Plant molecular biology • There would also appear to be strong basic science research programs at National Jewish in cell biology, oxidant biology and structural biology.
Supporting Statistics	• 31 NIH grants at UC-HSC in cellular and structural biology • 43 NIH grants in molecular, Cellular and Developmental Biology at UC-Boulder • 18 NIH grants in Biochemistry and Molecular Biology at CSU • UC-HSC 206 papers (1.71 PCR) in Molecular Biology and Genetics • UC-Boulder 336 papers (1.31 PCR) in Molecular Biology and Genetics • UC-Boulder 331 papers (1.59 PCR) in Cell and Developmental Biology
Key Institutions	• University of Colorado – Boulder • University of Colorado Health Sciences Center • Colorado State University • National Jewish Medical and Research Center

Field	RNA/Biochemistry
Field Definition	• Biochemistry – The scientific study of the chemistry of living cells, tissues, organs and organisms. • RNA – RNA (ribonucleic acid) is an information encoded strand of nucleotides, similar to DNA, but with a slightly different chemical structure. mRNA (messenger RNA) is the mediating template between DNA and proteins
Interview Identified Strengths	• Interviewees noted that UC-Boulder is regarded as the leading world center for RNA research—centered on the Colorado RNA Center. Particular expertise noted in: o RNA structure and function o DNA synthesis o Replication and molecular recognition o Cell signaling o Mass spectrometry o Functional proteomics • Highly developed investigational resources at UC-Boulder in spectrometry, NMR and x-ray crystallography. CSU also has significant infrastructure and resources, especially in NMR and MRI. • RNA expertise highly visible due to high-profile faculty such as Thomas Cech. • Commercial linkages from RNA technology into RNA drugs. • Colorado State interviewees noted the institutions strengths in plant biochemistry and related genomics work.
Supporting Statistics	• 30 NIH awards to UC-Boulder in chemistry and biochemistry • 28 NIH awards to UC-HSC in biochemistry and molecular genetics • 5 NIH awards to UC-HSC in biochemistry/biophysics and genetics • 18 NIH awards at Colorado State in biochemistry and molecular biology • UC-Boulder 1,250 papers (1.13 PCR) in Biochemistry and Biophysics • UC-HSC 412 papers (1.53 PCR) in Biochemistry and Biophysics
Key Institutions	• University of Colorado-Boulder (Biochemistry) • University of Colorado Health Sciences Center • Colorado State University

Field	Veterinary Medicine and Animal Sciences
Field Definition	• The science and art of prevention, cure, or alleviation of disease and injury in animals and especially domestic animals. •
Interview Identified Strengths	• Colorado State University is home to the 2nd ranked school of veterinary medicine in the U.S. (U.S. News ranking). • Special areas of expertise in the CSU vet school include: o Animal reproduction and reproductive biology (a focus that has resulted in considerable tech transfer) o Infectious diseases including: viral diseases, retroviruses, bacteria/myco-bacteria and prions o Toxicology o Cancer biology o Molecular and cellular integrated neurosciences o Equine sciences o Orthopedics and tissue engineering • Animal infectious disease research facilitated at CSU by excellent linkages to CDC Level-3 labs at the CSU Foothills Campus and the USDA vector-borne diseases lab in Laramie, Wyoming. Biosecurity links developing, facilitated by CSU extension services providing in-field monitoring, surveillance and diagnostics.
Supporting Statistics	• Colorado State University 557 papers (10.35 PCR) in Veterinary Medicine and Animal Health • Colorado State University 222 papers (3.12 PCR) in Animal Sciences
Key Institutions	• Colorado State University

Field	Endocrinology and Diabetes
Field Definition	The scientific study of the function and pathology of the endocrine glands (e.g. the thyroid gland, pituitary gland, etc.) and the clinical practice related to the health of the endocrine system and the treatment of diseases interacting with the system.
Interview Identified Strengths	• Endocrinology faculty at UC-HSC has 30 MD or PhD investigators. Research activities include basic research at the genetic and molecular level as well as clinical research. Focus areas include: o Molecular biology of pituitary hormone genes o The genetic determinant of hypothalamic hormone genes o Sex steroid hormone receptors o Thyroid hormone receptors o Pituitary cell signaling systems o Obesity o Insulin receptor gene, insulin signaling and the lipoprotein lipase gene • Barbara Davis Center for Childhood Diabetes contains leading clinicians, clinical researchers and basic biomedical scientists working to help patients with Type I diabetes. • Barbara Davis Center focus areas, identified by interviewees, include: o Identification of the immune cells (lymphocytes) responsible for the pathogenesis of Type I diabetes and the molecular targets of these cells within the endocrine pancreas o Screening and prediction research o Islet cell transplantation o Device trials and development o Eye disease related to diabetes. • Barbara Davis Center will be expanded to three times its size upon relocation to the Fitzsimmons campus. • CSU has researchers focused on neuroendocrinology and reproductive endocrinology.
Supporting Statistics	• 20 NIH awards to the Barbara Davis Center at UC-HSC • 33 NIH awards to UC-HSC in endocrinology/metabolism and diabetes • University Hospital Denver ranked 22nd in hormonal disorders (endocrinology) by U.S. News • UC-HSC 276 papers (3.08 PCR) in biological research in Endocrinology, Metabolism and Nutrition and 150 papers (3.85 PCR) in clinical research within the field • UC-Boulder 304 papers (1.59 PCR) in biological research in Endocrinology, Metabolism and Nutrition and 163 papers (1.96 PCR) in clinical research within the field
Key Institutions	• Barbara Davis Center for Childhood Diabetes • University of Colorado Health Sciences Center • University of Colorado Boulder • Colorado State University

Field	Psychiatry
Field Definition	The medical specialty concerned with diagnosis and treatment of mental disorders.
Interview Identified Strengths	• The University of Colorado Department of Psychiatry is a well funded and broad program with research work focused in the following areas: o Substance dependency, including mechanisms of increased vulnerability to substance dependency, genetic/phenotypic studies and pharmacologic approaches to rehabilitation o Developmental psychobiology o Indian and Native American psychiatry o Early development studies including basic research in socio-emotional development o Neuropsychiatry and traumatic brain injury, including brain-behavior relationships and neurologically based cognitive, emotional and behavioral disturbances o Schizophrenia including genetic and neurobiology studies, nicotine linkages, therapeutic approaches and drug evaluation.
Supporting Statistics	• The University of Colorado Department of Psychiatry has 52 NIH awards • UC-HSC 110 papers (2.33 PCR) in Psychiatry • UC-Boulder 152 papers (1.50 PCR) in Psychiatry
Key Institutions	• University of Colorado Department of Psychiatry and Colorado Psychiatric Health.

Secondary Strength Areas

Field	Nutrition and Metabolism
Field Definition	**Nutrition** – The study of the food and liquid requirements of humans or animals, consisting of the taking in and metabolism of food materials whereby tissue is built up and energy liberated. **Metabolism** – The sum of the chemical and physical changes occurring in tissue consisting of anabolism (reactions converting small molecules to large) and catabolism (large molecules to small).
Interview Identified Strengths	• The University of Colorado – Colorado Springs is in the process of forming a Metabolics Institute. The campus contains leading experts in immune-mediated cell death, tumor immunology; cellular metabolism and cannabinoids and free radicals. • The Colorado Center for Human Nutrition is located at UC-HSC and is funded by a $5.5 million grant from the National Institute of Diabetes, Digestive, and Kidney Diseases. Focus areas include: o Obesity (obesity and diabetes) o Development (developmental aspects of nutrient utilization and function) o Micronutrients (micronutrient absorption/bioavailability) • The Center for Human Nutrition is equipped with substantial core lab facilities including: o Energy Balance Core laboratory measuring nutrient utilization, energy intake and expenditure, and body composition o Metabolic Core laboratory investigating disorders of insulin action o Molecular/Cellular Core laboratory developing primary and stable cell models used for studying nutrient/hormone interactions during substrate metabolism. o Mass Spectrometry Core laboratory using stable isotopes to study nutrient metabolism. • Colorado State University's Department of Food Science and Human Nutrition has programs in nutrition research. • Ongoing research into plant physiology at UC Boulder offers insights into the genetic factors relating to the development of nutritional benefits in plants.
Supporting Statistics	• 6 NIH grants to the Center for Human Nutrition at UC-HSC • 2 NIH grants to Food Sciences and Human Nutrition at CSU • UC-HSC 276 papers (3.08 PCR) in biological research in Endocrinology, Metabolism and Nutrition and 150 papers (3.85 PCR) in clinical research within the field • UC-Boulder 304 papers (1.59 PCR) in biological research in Endocrinology, Metabolism and Nutrition and 163 papers (1.96 PCR) in clinical research within the field
Key Institutions	• University of Colorado Health Sciences Center • University of Colorado – Colorado Springs and Boulder • Colorado State University

Field	Biomaterials
Field Definition	The development and study of materials compatible for implantation within the human body.
Interview Identified Strengths	• The University of Colorado-Boulder has biomaterials research taking place, predominantly within the field of chemical engineering. Primary emphasis is on polymeric biomaterials and photopolymerization technologies (with a joint center established between UC and Univ. of Iowa for photopolymerization). There is a direct linkage in polymeric biomaterials between Chemical Engineering and the UC School of Dentistry. Also use of polymers for tissue engineering scaffolding with current efforts focused on heart valves. • Expertise in polymers likely to beneficial to a broad range of biomedical/biological applications. The most recent national research in gene therapy, for example, has received preliminary success using polymer-based vectors. • Biomaterials also being facilitated at UC by NASA sponsored BioServe Space Technologies working on testing/production of biomaterials in zero-G space. A joint project with the Colorado School of Mines. • Colorado State University has a lab working on biomaterials design especially on the molecular structures of biomaterial surfaces (polymers and plastics and interaction with cells and bacteria). Also doing work on micro-array diagnostic technologies and fundamental aspects of surface chemistry.
Supporting Statistics	• Colorado ranks 17th in the nation (FY2000) by the NSF in Bioengineering.
Key Institutions	• University of Colorado – Boulder • Colorado State University

Field	BioMEMS
Field Definition	BioMEMS Biological MicroElectro Mechanical Systems: Encompasses all interfaces and intersections of the life sciences and clinical disciplines with microsystems and nanotechnology. Covers microfluidics, novel materials for BioMEMS, biochips, tissue engineering, nanotechnology, surface modification, implantable BioMEMS, nanosystems for drug delivery, protein arrays, point-of-care diagnostic techniques.
Interview Identified Strengths	• Growing number of faculty at UC-Boulder focused on BioMEMS representing collaboration across mechanical engineering, electrical engineering and aeronautics. • Provides both a polymer and silicon based applications with emphasis on use of BioMEMS as sensors and actuators, for thermal analysis and for packaging of devices. • Development of nanostructured materials for biomedical sensor applications. • The University of Colorado-Boulder has a project called MicroElectronic Devices in Cardiovascular Applications which is working to advance the study of MEMS for early diagnosis and improvement in cardiovascular treatment. • BioMEMS work is being pursued in collaboration with neuroscience for creation of invasive devices and neurosensors. • Longstanding focus on use of bioelectromagnetics to probe function and develop diagnostics and therapeutics.
Supporting Statistics	• Electrical engineering at UC-Boulder recorded 147 publications and a citation per publication rate 49 percent above the national average. • Mechanical engineering at UC-Boulder recorded 205 papers and a citation per publication rate 112 percent above the national average.
Key Institutions	• University of Colorado-Boulder

Field	Plant/Agricultural Biotechnology
Field Definition	The application of biology and agricultural sciences to the development of new plant strains with novel and beneficial qualities. Also, the application of plants/biomass to the production of drugs, chemicals, energy sources and other biotechnology applications.
Interview Identified Strengths	• Interviewees noted that Colorado State University is highly ranked in agricultural sciences, with an emphasis in the following areas: o Crop breeding (especially in Barley and Wheat), via traditional and genomic methods o Plant pest resistance, natural and via breeding and genomics approaches o Plant pathogen research (bacterial, fungal and insect) o Whole genome sequencing (successful work has focused on mosquitoes and the bacteria causing potato ring rot) • Emerging strengths at Colorado State University coming out of biology and plant molecular biology, with work on bioproduction via plant biochemical pathways and plant biosensing characteristics. • CSU also has a focus on biochemical, molecular and physiological studies of plant ribosome-inactivating proteins. Native herbal plants are being researched for antiviral activity and active constituets isolated. Research is also taking place on herbicidal activity mechanisms. • CSU's Center for Environmental Toxicology and Technology (CETT), an interdisciplinary group of toxicologists, pathologists, chemical engineers, biochemists, molecular biologists and chemists. Te Center is focused on Quantitative and Computational Toxicology, integrating biomedical research with computer modeling to perform physiologically based pharmacokinetics/pharmacodynamics modeling or biolgicaly based dose-response modeling. A major goal is to use the modeling as a predictive tool for toxicology of chemical or chemical mixtures to minimize the need for animal experimentation. • National Renewable Energy Laboratory in Golden is focused on the application of plant materials (biomass) for production of energy. The lab is performing biotech research related to biorefineries, biomass fuels and chemicals.
Supporting Statistics	• Colorado ranks 14th in RandD funding for agricultural sciences with $58.8 million in FY2000 funding • 1 NIH grant to CSU in bioagricultural science and pest management • Colorado State University 168 papers (1.71 PCR) in Plant Science • Colorado State University 110 papers (2.68 PCR) in Agriculture/Agronomyhhhhhh