Colorado Nanotechnology

Roadmap

2006

NO SMALL MATTER.

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Prepared by:
Gary Horvath, Principal Investigator
Business Research Division/Business Advancement Center
Leeds School of Business
University of Colorado at Boulder
UCB 420
Boulder, CO 80309-0420
303-492-8227
http://leeds.colorado.edu/brd

Colorado
Office of Economic Development and International Trade

University of Colorado at Boulder
Colorado LEEDS School of Business
BUSINESS RESEARCH DIVISION

DENVER
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Acknowledgments

In the most recent rankings by Lux Research, Colorado was ranked third in the United States in terms of nanotechnology potential. In the research conducted for this Roadmap, the project team determined why Colorado has a desirable environment for nanotechnology research and development, and how the state can best take advantage of the increasing impact this technology will have on our economy.

Colorado's unique combination of resources includes such assets as a vibrant cluster of technology-based companies with a strong entrepreneurial spirit, cutting-edge research conducted by universities and federal laboratories, a dynamic economic development community, strong technical training programs at colleges and community colleges, and a supportive group of service providers.

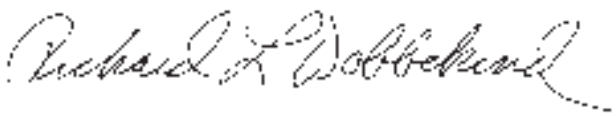
Several years ago a small group of individuals from varying disciplines decided that it was imperative to develop a grassroots initiative for nanotechnology in Colorado. The early leadership of this group recognized Colorado's potential and pushed to develop a roadmap. Their dream became a reality thanks to funding from the Economic Development Administration, the Office of Economic Development and International Trade, the Mayor's Office of Economic Development, the University of Colorado at Boulder, and support and input from more than 100 nanotechnology leaders in Colorado and other states.

On behalf of the Leeds School of Business and our coapplicant, the Colorado Nanotechnology Initiative, I would also like to thank our project team comprised of Gary Horvath, Karen Eye, and Dr. Mary Ann Roe. The work of the team has been supported by Business Research Division staff members Cindy DiPersio, Terry Rosson, and John Krebs. In addition, the research team included graduate research assistant Brian Lewandowski and the following student research assistants: Brendan Hickey, Colin Hickey, Ginger Wolf, Luke Willoughby, Charles Nichols, Aaron Aikins, and Katie Vance. Special thanks also go to CU Publications and Creative Services for its help in producing this report and to the Office of Contracts and Grants at the University of Colorado for assistance with administering this project.

The project team worked closely with the Roadmap Advisory Task Force (RTF), a cross-section of business and education leaders involved in various industries that will directly impact the development of nanotechnology in Colorado. RTF members include Rich Bolin, Dr. Linda Bowman, Dr. Ellen Fisher, Preston Gibson, Booker Graves, Griff Kundahl, Dr. Randall (Randy) Levine, Dr. Roop Mahajan, Michael L. Drapkin, Dr. Arlen Meyers, Dr. John Oakey, Dr. Kent Rochford, Christine Shapard, and Debbie Woodward.

As an individual who has followed Colorado's economic fortunes for more than 20 years, I am excited about the role the state will play in developing and implementing nanotechnology in our global economy. I am encouraged by efforts to ensure that social implications are considered as part of its development. For Colorado to take advantage of this extraordinary opportunity, it is necessary that strong leadership be present. I am confident that the combination of the excitement generated by the creation of the Colorado Nanotechnology Alliance and the hiring of its executive director will serve as a guiding force in engaging and informing individuals from all walks of life about this emerging technology.

Indeed, this is no small matter for Colorado!



Associate Dean for External Relations, and
Director of the Business Research Division
Leeds School of Business

COLORADO NANOTECHNOLOGY ROADMAP

SUMMARY PRESENTATION

Project Purpose and Layout

Colorado's nanotechnology roadmap was designed with the purpose of leveraging existing nanotechnology investment, assets, research, and human capital in the state to facilitate the growth of an emerging nanotechnology cluster. Outcomes of the project includes a nanotechnology roadmap, a condensed roadmap miniplan, a database of companies, laboratories, and universities involved in nanotechnology, a database of 500 national nanotechnology companies, a capabilities inventory report for Colorado, a primary metrics report, a secondary metrics report, and web site content for the Colorado Nanotechnology Alliance (CNA).

This miniplan serves as a summary of the comprehensive Colorado Nanotechnology Roadmap. It is comprised of nine main sections: introduction, state investments in nanotechnology, importance of nanotechnology to Colorado's economic future, Colorado's competitive position in nanotechnology, Colorado nanotechnology roadmap, Colorado situational analysis, three-year strategic action plan, conclusions, and a call to action.

Introduction

Nanotechnology is no small matter when it comes to economic development. Early predictions of a $1 trillion nanotechnology market by 2015 are eclipsed by current Lux Research projections indicating that emerging nanotechnology applications will affect nearly every type of manufactured good over the next 10 years, and be incorporated into 15% of global manufacturing output by 2014, totaling $2.6 trillion. Total global demand for nanoscale materials, tools, and devices reached an estimated $7.6 billion in 2003. With nanotechnology markets expected to grow at an average annual growth rate of 30.6%, market demand is expected to total $28.7 billion in 2008.

Governments around the world have invested billions in nanotechnology research and development (R&D) with the goal of capturing a share of the economic and social benefits promised by this science. For more than 25 years the United States has directly and indirectly invested in nanotechnology, and in 2001, the National Nanotechnology Initiative (NNI) was established to coordinate federal agency investments in nanotechnology R&D. The $1.2 billion proposed budget by the administration for 2007 will bring total U.S. investment since the NNI was established to more than $6.5 billion.

This science of manipulating extremely small particles (1–100 nanometers) of matter is expected to change almost every product on the market today and the way those products are manufactured. At least 200 consumer products are already on the market, along with many nano-based nonconsumer and intermediate products.

This enabling technology cuts across all industries, with applications in electronics, aerospace, biomedicine, defense, homeland security, information technology, environmental protection, energy, consumer goods, textiles, agriculture, and others. The technology will not only continue to improve products across this broad range of industries, but scientific breakthroughs are expected to result in revolutionary advances in medicine, energy, environment, advanced materials, and others.

"Biotechnology created more than 400,000 jobs from 1979 to 1999. Nanotechnology promises a far greater economic impact because it can affect not just biologically derived products, but all manufactured goods" (F. Mark Modzelewski, Managing Director, Lux Research, www.luxresearchinc.com/press/RELEASE_econ.pdf, January 25, 2005).

State Investments in Nanotechnology

"It's not how we do this but what will happen if we do nothing. We cannot afford to be left behind."

Sen. Florence Shapiro, R–Texas (*Express-News* Austin Bureau, March 2, 2005, http://www.txti.org/docs/TETF_Articles_Info.pdf)

The passage of federal legislation establishing the NNI, and predictions of seven million U.S. jobs generated by 2015, has led many states to create their own nanotechnology economic development programs. Early funding commitments by state governments and industry partners provided an advantage for these states in the competition for federal grant funds to build nanotechnology research capabilities and facilities.

With an eye toward protecting and growing current technology-based economies, more and more state governments have assessed their

position and decided they could not afford to sit on the sidelines while others passed them by. According to Lux Research, state and local governments in the United States invested more than $400 million in nanotechnology development in 2004 alone. At stake is a share of future economic growth for technology industries bringing professional jobs with current salaries averaging $97,978 (*Small Times*, 2006).

State investments in technology-based economic development, especially new technologies, should be viewed as "patient investments," with economic returns expected in 10 or even 20 years or more. In the near term, however, state investments in nanotechnology are already generating economic returns, including construction of new university research facilities, attraction of large research funding awards, and new industry partnerships to commercialize technologies with resulting job creation and retention.

"If we don't get in early on nanotechnology, we will miss an incredible opportunity.… The nanotechnology revolution is going to happen. The question is: Will California lead it?"

Steve Westly,
California Blue Ribbon Panel on Nanotechnology

For example, Purdue University developed the state-of-the-art Birck Nanotechnology Center by leveraging $5 million of state funding to attract another $46 million in private and federal dollars. In another example, a recent assessment of New York's $7 million investment in the University at Albany's Center for Advanced Technology in Nanomaterials and Nanoelectronics reports $1.1 billion in economic impact and the creation of 1,104 jobs and retention of 384 jobs (http://albany.bizjournals.com/albany/stories/2006/02/27/daily5.html).

"If we invest in things at the seed level, that's how you grow a knowledge economy.… Although $25 million is a paltry sum compared with the hundreds of millions that states such as Texas have poured into attracting cutting-edge technology businesses, it's a start."

Arizona Governor, Janet Napolitano (*The Arizona Republic*, January 18, 2006)

Leadership by state governors, legislators, and Congressional representatives has encouraged and assisted the growth of strong state initiatives for economic development with funding from federal and state sources. In the forefront are Senators George Allen (R–Virginia) and Ron Wyden (D–Oregon), who sponsored the 21st Century Nanotechnology Research and Development Act and initiated the bipartisan Congressional Nanotechnology Caucus.

"I am increasingly convinced that U.S. economic competitiveness in the global marketplace depends on success in developing a vibrant and innovative nanotechnology community. For my part, I am committed to ensuring that Virginia and the country play an important leadership role in this next revolution."

Sen. George Allen, R–Virginia (http://www.issues.org/21.4/allen.html)

While some states have been able to invest heavily in nanotechnology, others have struggled with tight budgets and fiscal constraints. As economies improve and funds become available, investing in the development of a nanotechnology cluster could mean the difference between insuring that a state has a robust technology-based economic future and risking the loss of key current technology industries and jobs to other regions or countries.

Importance of Nanotechnology to Colorado's Economic Future

Nanotechnology will undoubtedly impact the economy of the world; it will impact the economy of the United States and of every state, city, and county. It will impact every citizen in our nation! Governments with the foresight to invest now will reap the future economic growth already evidenced by early commercialization of this technology. Those states that seek to provide the high-salaried jobs inherent in a technology-based economy must ensure nanotechnology research excellence in their universities, education of a twenty-first century workforce, and a business environment that supports entrepreneurs and companies that will develop and deploy new products based on this technology. There is no question that Colorado must invest now to maintain its technology-based economy and support future growth of the technology industries currently prominent in the state.

Colorado Nano-Industry Profile

Nanotechnology R&D is most commonly performed in the electronics, aerospace, homeland security, biomedical, defense, and energy industries.

Many Colorado companies already recognize the importance of this technology. Research of published literature, company web sites, and database information, along with Roadmap company survey results, indicate at least 75 companies in Colorado are currently involved in nanotechnology. Of these, 54 companies responded to the survey, verifying their involvement. Forty-three companies indicated that they currently conduct nanotechnology activities in the state, while 11 additional companies conduct nanotechnology activities outside Colorado. The survey respondents anticipate the growing importance of nanotechnology to their company profitability. All respondents believe that nanotechnology will be somewhat important within five years, and 32.6% think it will be critical to company profitability within 10 years.

Nanotechnology is already making a contribution to the Colorado economy. It is important to note that 39.5% of companies responding to the survey that are involved in nanotechnology already have nanotech products on the market. Based on this survey, it is estimated that there are 150 full- and 150 part-time workers in nano-specific technical positions. These firms contribute $14.2 million in R&D expenditures ($8.8 million of which are federal funds to Colorado companies via SBIR/STTR programs) to the Colorado economy.

The nanotechnology R&D being performed by Colorado firms has applications in many industry sectors; the most common are electronics (45.5%), aerospace (44.7%), homeland security (33.3%), biomedical

(33.3%), defense (27.3%), and energy (27.3%). These are prominent industry sectors in Colorado and form the foundation for the state's technology-based economy.

Economic Benefits of Companies Doing Nano Work in Colorado

A comprehensive examination of nanotechnology companies, which was based on secondary research and results from the previously mentioned survey, reveals a geographically diverse cluster. These companies are found in 20 cities and 11 counties in Colorado. The cities with the greatest concentration of companies are Boulder (20.0%), Denver (12.0%), Golden (12.0%), Longmont (10.7%), Colorado Springs (9.3%), and all others (36.0%). The counties with the greatest concentration of companies involved in nanotechnology are Boulder (33.3%), Jefferson (26.7%), El Paso (9.3%), Broomfield (6.7%), Denver (6.7%), and all others (17.3%).

The 75 companies identified through surveys and research have estimated total employment of 19,118, with a median of 14.5 workers. Almost 90% of companies involved in nanotechnology fall under NAICS manufacturing (NAICS 31–33), and professional, scientific, and technical services (NAICS 54) sectors.

TABLE 1
COLORADO COMPANIES INVOLVED IN NANO BY NAICS SECTOR

NAICS Sector	Number of Companies	Percentage of Companies
Professional, scientific, and technical services (54)	35	46.7%
Manufacturing (31-33)	32	42.7
Wholesale Trade (42)	5	6.7
Other	3	4.0
Total	75	100.0%

It is estimated that the annual sales of companies in the Colorado nanotechnology cluster totals approximately $5.9 billion. The companies in this cluster have median sales of $4.5 million, although 80% of that total is from only four companies. About one-third of the companies have annual sales less than $1 million, and roughly one-half have annual sales less than $5 million.

An analysis of employee wages using NAICS codes and ES-202 data suggests that the average wage for workers in industries impacted by nanotechnology is $55,270 compared to an estimated average state wage of $40,280. The average wage paid to nanotechnology workers is estimated to be 37.2% greater than the average state wage. Estimated 2006 total wages paid to employees of companies identified in the cluster are $1.1 billion, or about 1.2% of projected 2006 state wages.

TABLE 2
ESTIMATED ANNUAL SALES FOR COLORADO NANO CLUSTER COMPANIES WITH FEWER THAN 250 EMPLOYEES

Employee Group	Number of Companies	Percentage of Companies	Total Sales (Millions)	Percentage of Sales
1-4	23	30.7%	$17.9	0.3%
5-9	6	8.0	13.1	0.2
10-19	13	17.3	58.6	1.0
20-49	17	22.7	182.2	3.1
50-99	5	6.7	115.6	2.0
100-249	4	5.3	216.9	3.7
250+	7	9.3	5,336.3	89.8
Total	75	100.0%	$5,940.6	100.0%

Colorado's Nanotechnology Research Base

In addition to the above-mentioned industry sectors, Colorado's research base supports nanotechnology, with strengths in converging technologies such as bioscience, information technology, and optics/photonics. University and federal laboratory research are critical to support nanotechnology economic development in many ways.

- Basic research conducted at these institutions is the source of scientific breakthroughs and solutions to technological barriers that facilitate later commercial innovations. While industry may join in sponsoring basic research, it is not economically feasible for companies to pursue initial long-term, high-risk basic research alone.
- High-quality research faculty and laboratory facilities enable universities to be more competitive for federal research grants, which not only brings more revenue to the state but also enhances and expands research capabilities.
- Researcher and facility capabilities provide important assets to companies that may lease expensive facilities and equipment for a targeted research effort, contract for specialized researcher services not available within the firm, or enter into a research partnership with the university or federal laboratory.
- Technology developed within a university or federal laboratory may be licensed to a new company that locates nearby in order to benefit from the expertise of the developing researcher(s).
- Research conducted at universities and federal laboratories provides experience and training for post-doc, graduate, and undergraduate students who gain scientific knowledge and research skills that are essential to building the state's workforce.

Well over 80% of the federally funded nanotechnology research in Colorado universities is currently conducted within the University of Colorado and Colorado State University systems. In addition, about 15% is conducted at the Colorado School of Mines.

The Roadmap project completed an inventory of nanotechnology research facilities and equipment, as well as researcher expertise at Colorado universities and federal laboratories. This detailed information will be available through the CNA web site to companies and research institutions. Colorado is fortunate to have significant capabilities to support increased nanotechnology research.

A recognized center of the NNI, the Center for Extreme Ultraviolet Science and Technology at Colorado State University (CSU) in Fort Collins (http://euverc.colostate.edu/) is funded primarily by the National Science Foundation (NSF) Engineering Research Centers (ERC) Program. Founded in 2003, the center partners with CU-Boulder and the University of California at Berkeley, and explores optics in the extreme ultraviolet (EUV) region of the spectrum to enable work with advanced electronic circuits and nanoscale machines. The EUV lithography this center offers is growing in demand for use in manufacturing computer chips. By 2009, the center expects to be making 19GHz microprocessors. The EUV ERC has developed a one-of-a-kind, soft X-ray laser that provides high-resolution imaging and analytical capabilities for nanotechnology research (http://www.nanotechbriefs.com/blog/apps_tm2_0306.html).

In the fall of 2006, the University of Colorado at Boulder and National Institute of Standards and Technology (NIST-Boulder) received preliminary notification of a Defense Advanced Research Projects Agency (DARPA) award to establish a research center as a national resource for nanotubes/nanowires integrated with microelectromechanical systems. This annual $1.5 million multiyear research program is supported by industrial sponsorships and university matching funds.

The DARPA Center adds to existing research programs and facilities in the University of Colorado system, including the Micro/Nanofabrication Research and Teaching Laboratory (http://mrtl.colorado.edu/), a shared user facility that opened in the spring of 2006. An existing facility, the Center for Advanced Manufacturing and Packaging of Microwave, Optical, and Digital Electronics (CAMPmode), is an NSF Industry–University Cooperative Research Center that focuses on the development of enabling technologies and solutions for design and packaging of microsystems.

The Colorado School of Mines (CSM) in Golden has equipment and expertise in the synthesis, processing, and characterization of nanomaterials and nanomanufacturing. More than 100 companies are involved in the university's materials-processing research, many of which deal with nanomaterials synthesis, processing, and characterization. CSM nanoscale research applies to many industries, including agriculture/food, consumer goods, defense and homeland security, environment, energy, and medicine.

The University of Denver (DU), which is a private university, has been involved in leadership for the state nanotechnology initiative. The institution has 10 faculty whose research work includes nanotechnology. They are currently involved in three federally funded nanotechnology-related research projects. DU is in the process of raising funds to add significant new laboratory facilities.

The U.S. Air Force Academy in Colorado Springs reports nanotechnology facilities and research geared to information technologies, and defense and homeland security interests. Modest research efforts at the University of Northern Colorado (in Greeley), Colorado State University at Pueblo, and Fort Lewis College (in Durango) provide hubs for future nanotechnology development around the state.

Federal laboratory resources support and complement the university network. Significant nanotechnology research capabilities and facilities are provided by the National Renewable Energy Laboratory (NREL) in Golden, and NIST in Boulder. They offer research expertise and facilities for nanotechnology applications in clean energy, and nanomaterial characterization and measurement, respectively.

A fully developed statewide network of nanotechnology centers of excellence at universities will provide the scientific basis for future spin-out firms, technology licensing for commercial use, and sponsored research to support company R&D. Furthermore, companies licensing nanotechnology from universities often locate near the institution in order to access the university researchers' expertise to continue the development and commercialization of the technology. Therefore, a strong network of university and federal laboratory nanotechnology centers of excellence is an important economic development asset for attracting new firms and supporting existing companies.

In addition to this network of facilities, the research institutions will need to combine resources and efforts to develop a centralized user facility available to all universities and industry. This facility would contain very specialized and expensive laboratories and equipment that could not feasibly be duplicated within the state.

Colorado's Competitive Position in Nanotechnology

External Assessments of Strengths and Weaknesses

According to many external assessments and reports, Colorado is well-positioned to compete in a technology-based economy. For example, the Milken Institute's annual science and technology index, which is comprised of five categories, ranked Colorado third overall among the 50 states in measures that support a technology economy. Within this index, Colorado places:

- First in human capital by such measures as educational attainment and SAT scores
- Second in technology concentration (clusters, new firms, commercialization, etc.)
- Third in research and development inputs (federal, university, industry R&D)
- Fourth in risk capital (venture capital, IPOs, patents)
- Fifth in science and technology workforce

Both *Small Times* and Lux Research rank states based on their nanotechnology economic development. While Colorado has yet to reach the top 10 in the *Small Times* ranking, the state was ranked third by Lux Research in a 2005 report. Lux measures the level of nanotechnology activity and general technology development strength and potential. The initial scores are then applied on a per capita basis. Because of the per capita consideration and the ranking based on potential, Colorado ranked third following Massachusetts and California. Other states in the top 10 are Virginia, New Mexico, New Jersey, Connecticut and Maryland (tie), Illinois, and New York (http://www.luxresearchinc .com/press/RELEASE_ econ.pdf, January 25, 2005).

Lux indicates that these leading nanotechnology states have three things in common. First, they involve all elements of the cluster in developing nanotechnology initiatives; second, they focus on commercialization; and third, they build on their strengths. These states also have a high level of nanotechnology activity with a strong track record in commercializing technologies. Each state also has its weaknesses, with Colorado's primary weakness identified as a low level of state funding (http://www.luxresearchinc.com/press/ RELEASE_econ.pdf, January 25, 2005.)

In analyzing Colorado's competitive position, the Roadmap research team and taskforce compared the state to benchmark states on a variety of metrics that support a technology economy. These measures were used to compare Colorado to seven "top nano" states (California,

New York, Massachusetts, Texas, Pennsylvania, Illinois, and New Mexico) and seven "peer" states (Arizona, Indiana, Oregon, Utah, Oklahoma, Wyoming, and North Dakota). Leader states are those ranked high in nanotechnology development by Lux and *Small Times*. Peer states were selected based on comparable size, proximity, or economic commonalities. The table below highlights Colorado's strengths and weaknesses compared nationally and to benchmark states on factors that characterize Colorado's economic, educational, technological, and innovative climate.

TABLE 3
HIGHLIGHTS OF COLORADO NANO STRENGTHS AND WEAKNESSES

Metric	Strengths	Weaknesses
Workforce Development		
Education	Led the nation with high SAT and ACT scores per graduates (2003), ranked in the top half of states for NAEP math and reading scores, ranked 2nd in percentage of population with bachelor's degrees or higher (2000)	Ranked 48th in state and local support for higher education per capita (2005) and 32nd in K-12 per pupil funding (2003-2004), and only 70.6% of high school students graduated in 2002
Business Growth		
State production	1st among peer and leading-nano states for tech gross state product (GSP) as a percentage of total GSP (2003), ranked in the top 10 for real and nominal compound annual growth rate of GSP from 1997-2005	Ranked low in value added manufacturing and value of shipments (2004)
Personal income	Ranked high (10th in nation) in per capita personal income (2004)	Ranked 49th in per capita personal income growth from 2000-2004
Employment	1st among peer and nano-leading states in high-tech worker concentration (2005)	Ranked in the bottom one-third of states for rate of employment growth (2000-2004)
Research and Technology Transfer		
Research and development	Ranked 5th in the nation in SBIR awards (2004), 8th in the number of patents per capita (2004), and in the top one-quarter of federal and industry R&D obligations per capita (2000)	Ranks below national leaders in total number of nano patents since 1976
Research funding	19th in the nation in total federal R&D funding (2003) and 17th in National Institutes of Health funding (2003)	Ranks below national nano leaders and some peer states in National Science Foundation nano R&D funding since 2000
Science and Technology Index	Ranked 3rd nationwide on the index (2004)	Ranked above peer states, although Colorado's rank has fallen since 2002 and most peer states show significant ranking improvement
Cost of doing business	Ranked in the bottom half of states in the cost of doing business index (2005), which means Colorado has a low cost of doing business	
Venture capital	Ranked 10th in the nation for venture capital investment dollars and deals (2004)	

In addition, the research team compiled available data on state expenditures to support nanotechnology economic development. The table below compares benchmark states' investment in nanotechnology by total amount and on a per capita basis. These estimates include amounts allocated directly to nanotechnology programs and facilities, as well as amounts budgeted for broader technology programs and incentives that *specifically* included nanotechnology. Data are based on available published information from multiple sources and conversations with nanotechnology and economic development leaders in each state and provide some basis for comparison.

TABLE 4
BENCHMARK STATES
COMPARATIVE NANOTECH INVESTMENTS
2002–2008
(In Millions)

	Total State Investment (High to Low)	Investment per Capita
Leader States		
New York	$750.00	$38.94
Texas	$300.00	$13.17
California	$100.00	$ 2.77
Massachusetts	$ 45.00	$ 6.90
Illinois	$ 44.10	$ 3.47
Pennsylvania	$ 42.00	$ 3.38
New Mexico	$ 14.00	$ 7.36
Peer States		
Utah	$ 76.60	$31.68
Arizona	$ 35.00	$ 6.82
Oregon	$ 28.00	$ 7.79
North Dakota	$ 20.00	$31.47
Indiana	$ 5.00	$ 0.80
Oklahoma	$ 4.63	$ 1.31
Colorado	$ 0.05	$ 0.01
Wyoming	$ 0.00	$ 0.00

Source: Data extracted from the main Roadmap report.

On both an actual and per capita basis, Colorado is clearly lagging behind all benchmark states (except Wyoming) in support for nanotechnology economic development. Fortunately, the amount of public sector investment is not the only indicator or generator of nanotechnology growth or potential. Without it, however, universities and companies engaged in development of this technology are likely to quickly fall behind others that have the resources to build a supportive infrastructure for research and commercialization.

Colorado Nanotechnology Roadmap

The Colorado Nanotechnology Roadmap Project was initiated to meet the need for a state nanotechnology plan to advance Colorado's competitive position in nanotechnology economic development. In November 2005, the project team established a broad-based taskforce to develop this customized three-year action plan to ensure Colorado's place in a nanotechnology-based economy. Features of the plan include:

In November 2005, the project team established a broad-based taskforce to develop a customized three-year action plan.

- Aggressive but attainable objectives that utilize and develop the state's assets;
- Priorities focused on challenges that must be addressed by involving many partners outside the direct influence of the cluster; and
- Supporting actions that chart a path from the resources and strengths available today to the investment and leadership needed to achieve the state's economic potential.

Colorado's Situational Analysis

The Roadmap action plan was developed considering Colorado's strengths, weaknesses, opportunities, and challenges based on input from focus groups, metrics comparing the state to benchmark states, and results of primary and secondary research.

The Roadmap presents these considerations in five functional areas that were determined to be essential to Colorado's nanotechnology future: Leadership and Resource Development, Research and Technology Transfer, Workforce Development, Business Growth, and Public Education and Societal Implications. Each section contains background information and analysis, objectives, and supporting actions. A brief summary of the five functional areas is presented here as an introduction to the complete action plan.

Leadership and Resource Development

From early 2003, Colorado's nanotechnology efforts have been led by a broad-based coalition representing academia, industry, state and local economic development, professional services, and workforce development. This initiative, which has developed widespread awareness of nanotechnology and involved all sectors of the nano cluster, is clearly one of Colorado's primary strengths. While volunteer efforts have focused attention on the opportunities and challenges Colorado faces, future leadership and direction is strengthened by recent funding to hire and support an executive director for the nonprofit organization, the CNA. This Roadmap presents the opportunity and challenge

for the cluster to accomplish the objectives in this action plan, stabilize ongoing funding, and update the Roadmap on a regular basis.

State government participated in supporting development of this Roadmap to provide a guide for public and private efforts. Perhaps the most pressing current challenge is to build on this support by preparing political leaders (i.e., governor, legislature, and Congressional delegation) to recognize the potential economic benefits of nanotechnology and the need to invest now in order to ensure that Colorado retains a strong technology-based economy.

It is critical that all research institutions and industries work together to plan and support a centrally located, common user facility that would provide equipment that is needed by all.

Research and Technology Transfer

Colorado universities and federal laboratories all have nanotechnology research capabilities. Some have specialized centers and facilities, while others use existing chemistry and engineering laboratories. Individual universities have plans to strengthen and expand their own research specialties and facilities to form a network of centers of excellence in nanotechnology. To the extent that these centers are not duplicative and serve the research needs of Colorado industry, they should be encouraged and supported.

It is critical, however, that all research institutions and industries work together to plan and support a centrally located, common user facility that would provide equipment that is needed by all. Development of this type of specialized center fosters research collaborations, provides a tangible asset to attract research funding and industry partners, and is visible evidence of the state's nanotechnology interests and capabilities. A collaborative effort of this type is perhaps the only way to justify and attract the needed resources.

A recognized weakness in the state is the lack of coordination of research assets. Actions recommended in this functional area call for a council of research institutions with industry counterparts to focus efforts, generate additional research funding, promote expanded research facilities, and increase the flow of technology to Colorado companies.

Workforce Development

Colorado is fortunate to have a highly educated workforce, many of whom are educated elsewhere. Technology-based companies in the state have little difficulty attracting Ph.D. scientists and engineers who want to live in Colorado. However, preparing a twenty-first century workforce will require *immediate* attention to our own lagging state education system and to the special multidisciplinary knowledge base needed for technical nanotechnology positions. In order to groom

our own citizens to qualify for high-wage technical jobs, the Roadmap calls for increased state support for K–12 science and math, teacher introduction to nanotechnology, student exposure to nanotechnology careers, community college programs for trained technicians, and university level courses in nanotechnology.

Business Growth

The ultimate goal of the Colorado Nanotechnology Roadmap is to advance Colorado's future technology-based economy through business attraction, generation, and growth, resulting in job creation and economic wealth for Colorado citizens. As an enabling, cross-cutting technology, nanotechnology is essential to the future growth of all of the state's technology industries.

Colorado has a strong technology-based economy, with companies and employment in many industries already involved in nanotechnology. Colorado also has a track record of innovation and entrepreneurship that creates new technology companies, a low cost of doing business, and a desirable lifestyle that is socially, culturally, and environmentally rich.

In addition to state government investment in infrastructure to support nanotechnology research and commercialization, companies currently involved in nanotechnology also expressed a need for services that can be provided by a fully staffed and operational CNA (i.e., networking, information sharing, exposure to investors, and access to research facilities and expertise). The Roadmap project provides CNA with outcomes that will directly support some of these needs.

Public Education and Societal Implications

Technology-based economic development has always fit well with the desire of Colorado citizens and leaders to maintain a beautiful mountain and forest environment supporting a cherished outdoor lifestyle, a strong tourism industry, clean air and water, high personal incomes, and sustainable economic growth. Consequently, Colorado is committed to set a national example with significant attention to the development and deployment of nanotechnology in a socially and environmentally responsible manner. It is recommended that a special council be established under CNA to ensure that this tenet is foremost in the implementation of all areas of the Roadmap.

Three-Year Strategic Action Plan

This Roadmap establishes a three-year action plan to guide the aggressive pursuit of economic growth based on the development and commercialization of nanotechnologies.

The Roadmap charts a path from the resources and strengths available today to the investment and leadership needed to achieve the state's economic potential. While the Roadmap covers a three-year period, a stable, long-term effort will be needed to fully recognize Colorado's potential and to ensure the future strength of our technology industry sector. There will be many changes over this three-year period: advances in the technology; changes in global, national, and state economies; and changes in the state's nanotechnology cluster. In 2010, it will be time to assess the progress made toward meeting the objectives set forth in the Roadmap and chart a future course of action.

The objectives, initially derived from input of the Roadmap Taskforce, focus groups, and the research team, were modified and quantified based on the results of primary and secondary research and subsequent reviews by the taskforce and by participants in several strategy sessions. As a result, the objectives presented here are based on a realistic assessment of current strengths, weaknesses, opportunities and challenges.

The Roadmap is organized in five functional areas: Leadership and Resource Development, Research and Technology Transfer, Workforce Development, Business Growth, and Public Education and Societal Implications. The achievement of each objective is intended to advance Colorado toward a primary outcome:

> *OVERALL DESIRED OUTCOME*: Establish Colorado as one of the top 10 states for nanotechnology-based economic development.

Measurement: The success of this Roadmap will be measured by the completion of 70% of objectives of the Colorado Nanotechnology Roadmap within the established timeline.

Leadership and Resource Development

Desired Outcome: **A strong, vibrant, and visible central organization will be created that will lead Colorado's nanotechnology development. It will be supported by top-level elected officials with broad-based participation by universities, industry, economic developers, educators, and the public.**

***Objective 1*—Leadership and Resource Development:** Develop and implement an action-oriented organizational structure supporting CNA leadership, systems management, and resource acquisition for Colorado nanotechnology business growth, research and technology transfer, workforce development, and public education and societal implications.

***Objective 2*—Funding:** Within three years, develop and implement a sustainable funding model for CNA staff, operations, and activities for 10+ years.

***Objective 3*—Marketing:** In 2006 and 2007, develop and implement an industry-driven communication plan targeted to all sectors of the Colorado technology community and to potential business partners worldwide that increases visibility of, and access to, Colorado nanotechnology capabilities, resources, and events.

***Objective 4*—Political Leadership:** By 2008, ensure political leadership for the endorsement, funding, and visibility of nanotechnology.

***Objective 5*—Strategic Alliances:** By 2008, the CNA will join with other technology sectors to develop and implement a shared vision to leverage and maximize federal, state, and local resources and to capitalize on opportunities for technology-based economic development across all cluster sectors (government, industry, research, workforce development, etc.).

***Objective 6*—Regional Strategic Alliances:** By 2009, Colorado nanotechnology leadership will establish or enhance three or more existing or new regional, national, or global collaborations that benefit the cluster with access to technology, talent, funding, research, and business partnerships.

Research and Technology Transfer

Desired Outcome: Expand the nanotechnology research base in Colorado and the utilization of that research by Colorado companies to create higher wage technical jobs and economic growth.

***Objective 1*—Network of Facilities:** Develop a central specialized user facility and expand Colorado's distributed network of multiple, nonduplicative, recognized nanotechnology research centers of excellence that support university and industry R&D needs.

***Objective 2*—Technology Transfers:** Increase the number of university and federal lab transfers of nanotechnology to Colorado companies by creating three more new Colorado-based spin-out firms and three additional licenses to Colorado firms in the three-year period 2006–2008.

***Objective 3*—Research Funding:** For the 2006–2008 period, federally funded nanotechnology research funding at Colorado universities and companies will exceed $35 million. This is 30% greater than the 2002–2005 baseline period.

***Objective 4*—Industry-University Collaborations:** The number of Colorado nanotechnology research collaborations—research partnerships, facility, or service-use agreements) between Colorado industry and university or industry and federal laboratories in the period 2008–2009 will be 30% more than the 2004–2005 baseline.

Workforce Development

Desired Outcome: Education and workforce training will offer all Colorado citizens the opportunity to develop the skills and knowledge needed to compete for high wage jobs in nanotechnology in order to meet requirements of companies utilizing nanotechnology.

***Objective 1*—Knowledge, Skills, Abilities:** Define and articulate workforce availability and gaps of knowledge/skills/abilities in the nanotechnology workplace in order to identify essential education and training required to fill those gaps.

***Objective 2*—Communication Plan:** Develop and implement a communication plan linking science and math competencies to career paths in nanotechnology for P–20 educators, parents, and students.

***Objective 3*—Integrated Education:** To meet the unique workforce needs of companies involved in nanotechnology, Colorado's system of workforce development and education will develop programs that are integrated across educational levels and disciplines.

***Objective 4*—Career Awareness:** Design and obtain funding for P–20 (preschool–college) demonstration projects that increase student awareness of and interest in nanotechnology careers.

***Objective 5*—Professional Development:** Create and provide access to a nanotechnology curriculum for educators, counselors, and administrators, and involve P–20 educators in a nanotechnology training program that includes tools and hands-on experience for integrating nanotechnology concepts into science, business, and liberal arts courses to increase student interest in science and technology careers.

***Objective 6*—Increased Degrees:** Increase the number of science, engineering, and technical degrees and certificates granted by Colorado universities and colleges in the 2006–2008 period by 5% compared to the 2002–2005 baseline.

Business Growth

Desired Outcome: Colorado will create, attract, and retain companies involved in nanotechnology research, development, production, and sales in a socially and environmentally responsible way.

Measurement: The goal of this action plan is to increase the size of the industry sector in 2009 compared to 2006 baseline data using the following criteria: double the net number of Colorado companies involved in nanotechnology, expand the net number of nano-related technical employees by 30%, and increase total revenue by 20%.

***Objective 1*—Attracting Business:** Increase and strengthen the industry sector by increasing or fostering new business relationships and attracting new companies that are compatible with Colorado's existing cluster.

***Objective 2*—Resource Access:** Increase the opportunities for Colorado companies involved in nanotechnology to access state, federal, and international resources essential to their success, including research capabilities and facilities; research, seed, and venture capital funding; management assistance; and information.

***Objective 3*—Increase Investment:** Increase investment in emerging nanotechnology business ventures. Between 2006 and 2008 five nanotechnology-based companies will receive external investments for pre-seed, seed, and institutional venture capital.

***Objective 4*—Legislative Agenda:** By 2009, a legislative agenda will be developed for changes in Colorado's business environment (tax, regulation, cost of doing business) that specifically address the unique needs of companies engaged in nanotechnology research, product development, production, or sales.

Public Education and Societal Implications

> *Desired Outcome:* Colorado will create a community that is knowledgeable and fully engaged with researchers, business leaders, and public policy officials in decisions and actions that protect against health and environmental risks while enabling development of economic and social benefits from nanotechnology.

***Objective 1*—Public Dialogue:** Public perceptions about nanotechnology will be informed through open dialogue and access to ongoing state-of-the-art research, information, and knowledge.

***Objective 2*—Workplace and Product Safety:** Researchers and workers at Colorado universities and companies will adopt high standards of voluntary health and environmental safety practices in the laboratory, workplace, and product life-cycle design.

***Objective 3*—Ethical and Societal Change:** Effective models to address ethical and societal concerns generated by the development and deployment of advanced technologies will be integrated into key community sectors: education, research, industry, and government.

The potential benefits of nanotechnology are enormous, and the greatest risk is the failure to act—and to act in time.

Conclusions

Nanotechnology is no small matter when it comes to economic development—it may, in fact, be the single most important driver of global economic growth over the next 10–20 years. While this science today is being applied to improve existing products, in the future it is expected to cause unprecedented change in the products we use and the way those products are made. As a result, it will change the way we work and the way we live. Change of this magnitude cannot be ignored. Business leaders, researchers, students, workers, politicians, educators, economic developers, journalists ... everyone has a stake in nanotechnology's successful and responsible implementation. The potential benefits of nanotechnology are enormous, and the greatest risk is the failure to act.

Nanotechnology is not some "new industry" that Colorado can afford to do without. It is an enabling technology that impacts all of the prominent technology industry sectors in the state: biotechnology, electronics/information technology, energy, defense/homeland security, aerospace, and more. This technology is generating market growth at a higher rate than either biotechnology or information technology. As such, it can be the catalyst for expanding every sector of our technology-based economy.

Colorado has the opportunity, the ability, and the responsibility to support and expand its existing technology economy by strategic investments in nanotechnology research, development, and commercialization. Success will require immediate attention and action to implement the Colorado Nanotechnology Roadmap.

Call to Action

The potential benefits of nanotechnology are enormous, and the biggest risk is the failure to act...and to act in time. While well ahead in many areas, Colorado is behind other states on some factors critical to building a strong competitive position. Immediate action is required if Colorado is to catch up in time to gain a solid position in the future economy. Colorado has the opportunity, the ability, and the duty to maintain a healthy technology-based economy, a high standard of living, and above average personal income for Colorado citizens. Responsibility for success does not rest solely with CNA but with the concerted efforts of many partners, including the following:

Political Leadership

Other states have already increased research funding, built new research facilities, expanded businesses and created high-wage jobs

through the leadership of governors, legislators, and Congressional representatives. Colorado's elected officials have the responsibility to initiate and support the policy changes and public financing necessary to ensure that Colorado universities, companies, and citizens share these economic benefits.

Research Institutions

Colorado universities and federal laboratories represent some of the state's most significant nanotechnology assets. They share a responsibility to coordinate, communicate, and open these assets to Colorado industry. In doing so, everyone will benefit from increased research funding, improved laboratories and equipment, more license and royalty income, and a quality educational environment.

Business Community

From an economic development perspective, the primary goal is to create jobs and wealth in the private sector. Companies of all sizes have a responsibility to their owners, investors, and customers to ensure responsible and ethical nanotechnology development, and an opportunity to work through CNA to communicate their business challenges and needs to educators and policymakers.

Economic Development

Nanotechnology has the potential to create economic growth in every geographic area of the state and in diverse industry sectors important to state and local economic development organizations. These organizations have a responsibility to promote Colorado's nanotechnology capabilities and resources to help local businesses grow and new companies relocate to the state.

Education and Workforce Development

Colorado must continue to invest in improving its educational system, from pre-K through higher education, with a focus on math and science education, interdisciplinary course content, ethics in business and science, and technology career preparation. Educators and workforce development professionals have a responsibility to work collectively for positive systemic change that better prepares Colorado youth for high-wage technology jobs.

Colorado Citizens

Nanotechnology promises to improve our quality of life with advances in medical diagnostic and treatment; clean energy and manufacturing; environmental monitoring and mitigation; faster, smaller, cheaper electronics; "smart," lightweight materials; and much more. Colorado's highly educated, technology-savvy citizenry has a responsibility to be fully informed and engaged in ensuring the responsible development and deployment of nanotechnology, and in planning and preparing for the social changes it will bring.

Debbie Woodward
Executive Director
Colorado Nanotechnology Alliance
1625 Broadway, Suite 950
Denver, CO 80202
303.592.4084
303.592.4061 (fax)
dwoodward@coloradonanotechnology.org
www.coloradonanotechnology.org

Colorado Nanotechnology Alliance

CNA is a broad-based statewide alliance of organizations that individually and together recognize the importance of nanotechnology and are committed to supporting its responsible development and deployment in our state. By its own charter, CNA is responsible for leading, motivating, educating, and coordinating the actions of many partner organizations for the benefit of all.

This is no small task.

The time to act is now!

Colorado
University of Colorado at Boulder