Choosing to Lead:

The Race for National R&D Leadership & New Economy Jobs

Case Statement & Core Technology Audit

The Massachusetts Technology Road Map and Strategic Alliances Study

2004

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Mass Insight Corporation is a public policy research and consulting firm that seeks to keep Massachusetts and its businesses and institutions globally competitive. The firm organizes client and leadership initiatives and uses communications, publications, policy research and public opinion polling to shape public-private dialogues. Mass Insight delivers policy results on issues where state actions and investments affect profitability, growth and new jobs.

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This Massachusetts Technology Road Map is a publication of Mass Insight Corporation, a Boston-based public policy firm dedicated to improving Massachusetts' economic competitiveness, in partnership with Battelle Memorial Institute's Technology Partnership Practice.

Research and Interviews:
Battelle Technology Partnership

Project Design and Management:
Mass Insight Corporation
William H. Guenther, President

Design and Production:
Joanna Manikas, Mass Insight Corporation

For information or additional copies, please contact:

Mass Insight Corporation
18 Tremont Street, Suite 930
Boston, MA 02108
tel: 617-722-4160
fax: 617-722-4151
email: insight@massinsight.com

www.massinsight.com

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User's Guide to the Massachusetts Technology Road Map

The technology road map is published under the title *"Choosing to Lead: The Race for National R&D Leadership & New Economy Jobs"* — a comprehensive road map with many key analyses to inform and help guide Massachusetts science and technology policies in the years ahead.

Case Statement & Core Technology Audit

A concise discussion of Massachusetts' current position in research and technology development and recommendations for actions to sustain Massachusetts' technology competitiveness.

- **Detailed analysis of the vulnerability of Massachusetts' technology position**, including recent trends in R&D funding and external challenges.
- **First ever detailing of core technologies** driving Massachusetts' economy with summary table on Massachusetts' competitive position across technology industry presence, talent generation and research excellence.
- **New Economy Agenda with specific suggestions for strategic alliances and investments** to advance the technology leadership and economic growth of Massachusetts and its regions.

Strategic University-Industry Alliance Opportunities

Identifies potential strategic alliances and collaboration networks in emerging technologies where Massachusetts is positioned to take a leadership role in research, development, commercialization and company creation while expanding the impact of research on regional economic growth across the state.

- An **opportunity statement for nine strategic alliance opportunities** with details on market potential, fit with Massachusetts and specific activities and state investments needed.
- Additional five initiatives detailed for further discussion on **technology connecting activities** to advance industry activity across regions of Massachusetts.
- This list of potential opportunities is not exhaustive, but rather suggests concepts that may ultimately lead to the development of new initiatives and investments.

Core Technology Analysis and Charts

First ever detailed assessment of the core technology areas driving Massachusetts' economy and competitive position.

- Explains the **methodology** for identifying core competencies.
- Presents the **results of sophisticated clustering analysis** across patent and research grant activities and input from extensive interviewing of university, teaching hospital and industry officials.
- **Analyzes the competitive position of Massachusetts** in each core technology area across technology industry, talent generation and research excellence.
- Offers **easy-to-read tables** summarizing Massachusetts' position in each core technology field.

Competitor State Technology Initiatives: Benchmarking Analysis

Identifies best practices of leading peer states and outlines their approaches to science and technology initiatives to jump start a discussion of strategies appropriate to advance technology alliances in Massachusetts.

- Summary of **best practices from detailed case studies** of leading peer states.
- **Detailed case studies** of science and technology approaches for California, New York, North Carolina and Pennsylvania.

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The following publications and materials are available on ***www.massinsight.com****:*

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Core Technology Analysis and Charts

Competitor State Technology Initiatives: Benchmarking Analysis

Directory of Major Massachusetts University and Nonprofit Research Centers

Massachusetts Technology Road Map PowerPoint presentation

Introduction

Massachusetts Technology Road Map and Strategic Alliances Study — Project Summary

*Through the **Science and Technology Initiative** of Mass Insight Corporation, a broad-based consortium of leading business, university, and economic development organizations came together to develop a technology road map for Massachusetts and to identify potential strategic alliances among public and private universities, teaching hospitals, government and industry which will maintain and expand the state's research, development and economic leadership in emerging technologies.*

At its heart this report is a road map for prevailing in an international competition for research, innovation and talent, and for supporting broad-based economic growth and new jobs across all regions in Massachusetts.

*The **Case Statement and Core Technology Audit** evaluates Massachusetts' research strengths across its universities, teaching hospitals and industry; summarizes competitive R&D issues; and makes recommendations for major stakeholders to maintain Massachusetts' national R&D leadership and create new economy jobs.*

Foreword

> *"It is incumbent on Massachusetts government, universities and industry to do a much better job of technology auditing and forecasting. We need to collaborate more effectively and develop a technology road map that looks five or ten years down the line. Without a road map and an economic development strategy, we run the risk of turning into Cambridge, England: we'll have isolated clusters of the very best university research and a number of small R&D firms but not the downstream production, service and support jobs that make a vibrant economy. We'll create all the new ideas – but others will get too much of the benefit."*
>
> *— Michael Best, university professor and co-director,*
> *UMass Lowell Center for Industrial Competitiveness*

For generations, the engine of the Massachusetts economy has been research and development. R&D stands at 4.5 percent of the state's economic output. This is almost twice as high as the figure for the nation.

It is R&D that drives the innovation economy-the talent, firms and industries that take the lead in lifting Massachusetts to a higher and higher position on the world-wide technology food chain. With each new wave of technological advance, Massachusetts' R&D base has enabled the state to remain a leader in emerging industries—from manufacturing to financial services to information technology to health care. Today, this innovation economy accounts for a quarter of the state's jobs.

But the R&D engine that underpins this progress is vulnerable. On three different measures of its national competitiveness in R&D, the state has lost market share: federal spending on R&D, industry spending on R&D, and university spending on R&D. It is also not keeping pace with key competitor states in attracting and retaining talent. And this loss of ground to other states occurs as Massachusetts becomes vulnerable to competition in R&D from other nations.

It might be tempting to be complacent. After all, these changes have occurred gradually. But complacency is a formula for economic disaster. Yes, these losses have occurred at merely an incremental pace. But this doesn't mean that the nature of the change they reveal is merely incremental. It isn't. Far from incremental, the change itself is a good deal closer to revolutionary—technological progress drives the destruction of previously successful businesses, industries and regional economies and the creation of new ones. Each leap forward offers new competitors an opportunity and threatens the economic basis of the existing leaders.

This global competitive struggle to be an attractive and effective site for the creation of new and commercially viable technologies has now entered a dramatically different era, one driven by changes in the nature of R&D. The sources of innovation have broadened across boundaries in two dimensions—that of the firm, as companies increasingly partner with external sources of innovation rather than relying mainly on internal research laboratories; and that of traditional scientific disciplines, as new breakthroughs require work across disciplinary boundaries.

These changes are driving **a new model of competition, one whose goal is to leverage innovation to drive economic growth within a state or region** *(see "The New Model of Competition." on page 6)*. It's a model that stresses the importance of intellectual collaborations and activities to better connect research with development and ultimately production and a commitment to developing the state's intellectual resources to promote development throughout the regions of the state.

The model looks not just to create a small number of jobs at the very top of the research food chain, but to drive innovation and job creation across the full economic life cycle—from research through development to sales, implementation and ongoing support.

The results of choosing, explicitly or by inertia, one or another economic strategy can be seen in a tale of two cities—Cambridge, England and San Diego, California.

Though Cambridge University has for centuries been a source of breakthrough discoveries, the Cambridge, England region has captured only the small firm R&D benefits of these discoveries—limiting its potential to create new jobs, new companies and major new industries locally.

San Diego, meanwhile, undertook a defined focus of building its university research base to help deepen and diversify its economy, repositioning the region after the economic shock of the end of the Cold War with growing businesses in telecommunications, software & computer services and biotechnology *(see "A Tale of Two Regions" at right)*.

The choice is between a research-centric economy that yields fewer jobs or a diversified one which leverages its research base as an economic asset for broader growth.

That diversified economy includes manufacturing and production, but not the type of mass production that is rapidly disappearing in the United States. The good news is that Massachusetts has rarely thrived on mass production of commodities. Our strength has been in precision machining and control of complex processes. The emerging areas of biotechnology and nanotechnology appeal to our strength in managing complexity, combining functions and features in new ways, and working at smaller and smaller scales of production.

It is fortunate for Massachusetts that those who understand the depth of these changes include the current chief executives of MIT and Harvard, who together led a half-day Life Sciences Summit last year. As Charles M. Vest, president of MIT, has noted: "other states have learned from us and are looking to replicate and expand upon the Massachusetts model. They are investing heavily to beat us at our own game. These states are making smart investments in their higher education systems, and forging strategic partnerships between their research universities and their core industries."

But these leaders are not alone in urging and in moving forward changes in how we compete. In May 2002, Mass Insight Corporation kicked off a **Science and Technology Initiative**, bringing together stakeholders from across industry, academia and government, with a strong recommendation that the state provide matching funds to support industry-university collaborations.

In October of 2002, five leading Massachusetts CEOs sent an open letter to the two gubernatorial candidates urging them to:

- Increase collaborations among public universities, private universities and Massachusetts businesses;
- Accelerate the development of the UMass system as a leading-edge technology university;
- Support initiatives that coordinate science and technology initiatives by private campuses with the public higher education system;
- Continue steps to improve K-12 math and science education;
- Play a more active role in seeking federal research funding.

This was followed by the distribution of the Mass Insight report *An Economy at Risk* in January 2003 and the passage of the legislative "Science and Technology Resolve" in April. Meanwhile, an alliance of industry, higher education, teaching hospital and government leaders

A Tale of Two Regions: Cambridge, England and San Diego, California

Cambridge: A Limited Research-Centric Economy

Building on the continued growth and advancement of Cambridge University, Cambridgeshire County has succeeded in stimulating a significant level of science-based entrepreneurship, but there has not been much in the way of impact on economic output or higher earnings.

In the Cambridge phenomenon, many technology companies, but not much job generation or economic impact. Michael Best reports that roughly 1,600 high tech companies exist in Cambridgeshire and many have links to Cambridge University. But these firms remain predominantly small, nearly half with less than five employees, 80% with less than 25 employees and only 3% with over 200.

Suma Athreye, of the Open University, in comparing Cambridgeshire, England with Silicon Valley (Santa Clara County)—each of similar geographic size—finds their economic scales vastly different. Regional economic output of Silicon Valley is six times that of Cambridgeshire, average earnings are more than a third higher in Silicon Valley and population is three times larger in Silicon Valley.

San Diego's Knowledge Economy: Using Research to Drive Economic Linkages and Economic Diversity

In the late 1980s and early 1990s, San Diego experienced enormous economic losses as a result of defense downsizing. However, unlike other regions that were economically devastated by the cutbacks, San Diego experienced rapid growth in the emergence of high-technology firms. Employment losses caused by the defense downsizing were replaced by the growth of three technology sectors: communications, biotechnology and pharmaceuticals, and software and computer services. These three clusters alone replaced the total number of direct jobs lost in defense manufacturing during this time.

Key to the emergence of San Diego is the ongoing and important relationship between UCSD and greater San Diego. Forty years ago, the University of California at San Diego (UCSD) did not exist as an operating institution. UCSD's research expenditures in FY 2000 totaled $518.6 million, placing it sixth among all U.S. universities. Working through an organizational infrastructure and mission that emphasizes the university role in the regional economy, *UCSD reports that over 40,000 jobholders in the San Diego economy are now its graduates*, many of them in the burgeoning number of high-tech companies that characterize the community. Through its nationally known CONNECT program, UCSD plays a major role in fostering the local entrepreneurial economy. Not surprisingly, the university technology transfer function places a heavy emphasis on commercializing faculty inventions through locally based startup companies. More importantly, the university created a labor pool of highly trained students in the emerging technology fields who would supply the region's growing industries.

brought together by Mass Insight in the Science and Technology Initiative took the next step in June by commissioning Battelle Memorial Institute to prepare this report.

While this report has been in preparation, leaders across the sectors have supported continuing progress.

- September 2003 saw Harvard and MIT convene the Life Sciences summit.
- In October 2003, early indications of the promise of collaboration were realized when UMass Amherst was awarded a $40 million Engineering Research Center, with the state's one-time $5 million match a critical element in their success.
- In January 2004, the $100 million Economic Stimulus Package was approved by the Legislature, providing a $20 million state matching grant program through the Massachusetts Technology Collaborative, a $25 million recapitalization for the Emerging Technology Fund which could also be used for matching funds, and $15 million for the John Adams Institute to promote regional technology development.

With this report, the Science and Technology Initiative takes the next step. Drawing on the findings of an assessment of the state's core technology focus areas and potential strategic opportunities for the future developed by the Technology Partnership Practice of the Battelle Memorial Institute, it spells out what steps the state must take in order to adopt and adapt the new competitive model and provides a framework for identifying investments to be made with the new state funding leveraging federal and private investments.

The choice is ours to make in Massachusetts. Through new partnerships and aggressive state support, we can choose to lead the nation in R&D and adopt economic strategies that use the research engine to drive broad economic growth in all regions of the state. Or, as Ray Stata, chairman of Analog Devices has said, "we can leave the future of our science leadership and our most promising industries to chance."

President, Mass Insight Corporation

John Armstrong

Chairman, Road Map Executive Advisory Committee
Vice President, Science and Technology, IBM (ret.)

William Terry, MD

Vice Chairman, Road Map Executive Advisory Committee
Vice President, Corporate Sponsored Research and Licensing, Partners HealthCare

As described on page 3 of this Foreword, the changes in global competition for national R&D leadership and new economy jobs have produced a new model involving strategic alliances between universities, teaching hospitals and industry and supported by state government. The following table outlines the key elements referred to in the road map study.

The New Model of Competition

The chief impetus for the rise of the new model of competition is a pair of changes that have occurred within the very nature of the realm of knowledge and discovery.

For one, corporations are now pursuing sources of innovation more broadly, rather than relying on internal research labs, and so this requires more partnering and collaborations with other companies, universities, teaching hospitals and federal research centers. Second, the growth of knowledge now follows new patterns. As a result, it doesn't always provide us with the convenience of flowing only within the boundaries of traditional academic disciplines, or even the broader categories of the intellectual work. "Old distinctions…—science versus engineering, basic science versus applied science, biology versus physical science, physical science versus information science, information science versus biology—are obsolete," notes Charles Vest, president of MIT. A corollary of the second is that the intellectual scope of the work that must be done in order to fulfill each of many of the great opportunities for innovation is vast in its extent. It spans a wide array of specialties.

As a response to these changes, the new model for a state to follow to achieve dominance in technological innovation displays several defining features:

- A strongly-stated commitment to the use of **technological innovation to drive economic growth** within the state. New-model states actively build their capacity and competitiveness in R&D for the express purpose of fostering the growth of successful new products, successful companies (new and existing) and good jobs. In their view, R&D is no longer a matter of importance just for people in lab coats. These states are also using it as the very foundation for their economies in the 21st century.
- An avidly-pursued commitment to establishing **intellectual collaborations**. Given how knowledge grows, and the vast intellectual scope of today's challenges and promises, it is now crucial to assemble varied teams of researchers -teams that cut across the lines of individual institutions as well as academic specialties. For this reason, the federal agencies that fund R&D are now setting explicit and implicit requirements for such collaboration, because it is increasingly essential if a research initiative is to hold promise of success. Other types of research sponsors are following suit. Research consortia, strategic partnerships, multi-disciplinary centers, multi-institutional alliances—these and other arrangements must be formed in order to meet the new imperative for collaboration.
- An aggressive commitment to the creation and use of what are known as **connecting activities**. These are activities that link the results of academic research to people who can turn these results into commercially viable goods and services. States use them as a way to make it more likely that the lion's share of the commercial benefits of the state's R&D will initially remain within the borders of the state. Connecting activities are performed by several different types of organization: incubators, for example, or partnerships between universities and industries…the case for them is well made by President Lawrence Summers of Harvard: *"(We) in universities are very poorly situated to bring products to market, to execute a whole set of tasks that are enormously socially important. And therefore, it is important to the success of this scientific enterprise that it be carried on by many different kinds of actors with incentives in close proximity to one another."*
- An active commitment to creating **strong regional economies**. Within states, some regions have lagged in economic strength and growth. But it is possible to jump-start a regional economy with a strategic infusion of R&D support, new forms of intellectual collaboration, and the appropriate connecting activities. Such regions can offer attractive costs and room for campuses and firms and industries to grow.
- A steady commitment to **leverage the value and use of the state's university.** If a state government wants to stimulate R&D-driven technological innovation, and capture a large share of its benefits within its own borders, and especially within specific regions, its best lever for doing so is its state university. It is also advantageous for a state to have a university whose research is world-class but whose first loyalty is to its home state. Many state universities also have multiple campuses, and some of the campuses serve regions that are in need of economic development. Those campuses can serve as the staging grounds for regional initiatives to turn R&D into new growth, new jobs, and new hopes.

In sum: the nature of the state-by-state competition for dominance in technological innovation has been transformed. With the wider and wider adoption and use of the new model, the means of competition have changed. At the same time, the number of contending states has grown. For both of these reasons, the intensity of the state-by-state competition has escalated.

Executive Overview

There are serious challenges to Massachusetts' continuing leadership in innovation that threaten the state's economic vitality. Addressing this problem is the mission of the broad science and technology initiative being undertaken by Mass Insight Corporation. This road map of core technology areas and strategic opportunities for Massachusetts suggests steps that will begin to address the problem while creating a culture of collaboration to promote prosperity across the state's regions.

Massachusetts is at a crossroads. The state could remain primarily a major center for high-level research—albeit one with less and less market share—and fail to capture downstream jobs from leading commercial research and early technology discovery efforts, similar to Cambridge, England. Or, the state can work smarter to drive broader economic activities across commercialization, product development and manufacturing through the type of technology collaborations, connecting activities and targeted capacity building found in leading new regions such as San Diego. This focus on ensuring broader economic activities also requires a close look at other economic competitiveness issues, such as state and local permitting regulations, cost of housing and overall tax levels.

Over the last sixty years, Massachusetts has built a technology-based economy by producing high value-added goods and services. It has stayed ahead of the competition in new waves of technology by tapping into its well-developed and robust research base. Despite not having the benefit of natural resources or growing population, Massachusetts has a key asset in its research base and the talented workforce it produces. The state has thrived because of its ability to translate new ideas generated by its research base into new products and services. The result has been a leading position in emerging industries and high quality jobs for its citizens across a spectrum encompassing research, product design, engineering, manufacturing and production as well as sales, marketing, finance and services.

Looking to the future, an in-depth analysis confirms what is visible on the surface—Massachusetts has powerful strengths across a range of core technology areas in research and education. Strength and depth is found in advanced materials, signal processing, computer sciences, sensing, optical and electromechanical devices and environmental sciences. In the life and medical sciences, Massachusetts is strong in genomics and proteomics and in disease-related research in immunology and infectious diseases, cancer, cardiovascular systems and the neurosciences. Massachusetts is also an emerging center of excellence in the cross-cutting areas of biomedical device technologies, renewable energy and nanotechnology fabrication.

But signs of vulnerabilities in Massachusetts' position in technology innovation and the need for new approaches to compete are evident.

Unlike an economic recession, where there are immediate job losses and business closings, the erosion of Massachusetts' competitive technology position will slowly threaten the economic vitality of the Commonwealth. It will be hard to see its full impact until it is too late to recover. As Dr. William Terry, vice president of corporate sponsored research and licensing at Partners HealthCare System, explains, "What we see

Massachusetts has been at the forefront of the major technological waves involving precision manufacturing starting from the mechanical period in the 1800s.

Over time, innovations in electrical, electronic, information and opto-electronics systems produced more complex products involving innovative new capabilities at ever smaller device sizes. Biotechnology and nanotechnology—each working at the molecular level—offer the next round of technology innovation.

Today, five of the nine key statewide technology innovation clusters identified by the Mass Tech Collaborative are found in manufacturing, including:

- Computer and communications hardware;
- Defense manufacturing and instrumentation;
- Diversified industrial support ranging from materials industries (paper products, plastics, metals, coatings, rubber) to machinery industries (industrial, electrical equipment);
- Healthcare technology including medical devices, biotechnology and pharmaceuticals; and
- Textiles and apparel.

today is just a symptom and the disease will become manifest 10 or 20 years in the future, unless we start the preventative measures now."

Massachusetts' Competitive Advantages in Innovation Are At Risk

While still a research powerhouse, Massachusetts has steadily been losing market share of the nation's R&D budget, across university research activities, federally-funded research activities, and industry research activities.

- In research conducted by universities and university-affiliated teaching hospitals, Massachusetts' share of all university research and development activity across the U.S. has fallen steadily since the mid-1980s, from 7.6 percent in 1985 to 6.9 percent in 2001.
- Similarly, the share of federal research funding awarded to Massachusetts—which supports universities, teaching hospitals, industry and federal research labs and research facilities in the state—declined from nearly seven percent in 1985 to 5.5 percent in 2001. Notably, despite impressive growth at the state's world-class research and teaching hospitals, funding for medical and life science research has not kept pace with the doubling of funding at the National Institutes of Health.
- Industry research and development activity, in sharp decline in the late 1990s with the dot.com bust, is at its lowest levels of national market share. By the end of 2000, Massachusetts' share of total industry research and development stood at 4.9 percent compared to 5.3 percent in 1985.

Of particular concern is the ongoing shrinkage in military facilities that threatens vital R&D facilities in Massachusetts. The Massachusetts Technology Collaborative points out that through FY 2000, Department of Defense (DoD) installations at Natick and Hanscom continued to see decreasing funding, making them more vulnerable to closure during the next round of Base Realignment and Closure (BRAC) However, FY 2001 data indicates strong growth in funding from DoD for its intramural research in Massachusetts, possibly in activities related to homeland security. Loss of either Natick or Hanscom would have a ripple effect through the state's R&D community and innovation economy that is much larger than reflected in the intramural funding numbers due to the large volume of work at Massachusetts institutions funded through these facilities.

Massachusetts is no longer a clear winner in the competition for talent. Recent Census findings indicate that Massachusetts is not keeping pace with key competitor states for 25- to 39-year-old, single, college graduates. A closer look at the competitive position of Massachusetts in talent generation across the identified core technology focus areas reveals:

- While Massachusetts is highly competitive in graduating PhDs, it falls well behind other states in the generation of associate degree graduates across core technology focus areas. These associate degree students are a cornerstone for the modern production systems and delivery of high-end services in information technology and medical care.
- The state is a major generator of graduates across the core technology focus areas, but generally the growth in degrees by specific technology areas is lagging in Massachusetts (often Massachusetts is declining faster than the nation). One exception is in computer sciences, where nationally the growth has been strong, and particularly so in Massachusetts.

Ultimately, both the creation of great research and the translation of research into products and services are accomplished by technically educated, talented people. Higher education graduates—from the associate through the PhD levels—carry innovation with them, making them the best mechanism for technology transfer. Despite Massachusetts' history as a magnet for college students, there are danger signs in its ability to attract and retain talent. Too many of Massachusetts' university graduates leave the state, taking their ideas with them. Massachusetts' recovery from the recent recession is predicted to be slower than that of the nation as a whole, further dampening a job market that is already significantly depressed. The high cost of housing and living is a further disincentive to remaining in Massachusetts.

Key competitor states have the benefit of a robust public research university system to complement private universities, partner with industry, and drive technology-based growth in all regions of the state. Massachusetts, while having launched a successful K-12 reform and investment effort, has been steadily decreasing its investment in higher education.

- Compared to New York, North Carolina and Pennsylvania—each of which also has strong private research universities—Massachusetts' public university research base is less than half their size. All five of the UMass campuses combined would rank as only the 42nd largest research university in the nation today with none of the individual campuses ranking above 94th in the nation.
- Massachusetts has the distinction of having the highest percentage decrease in state higher-education appropriations of all fifty states, not just for the current fiscal year, but over the past two years. The depth of the cuts in state funding for higher education in Massachusetts over the past two years—a 23% reduction—resulted in Massachusetts being the only state in the nation to record a decline in state funding over the past ten years. While Massachusetts decreased its spending on higher education by 5.3% from FY 1994 to FY 2004, California increased its spending by 91.8%, North Carolina by 50.1%, Pennsylvania by 27.7% and New York by 21.6%.
- Not surprisingly, Massachusetts is also losing ground in its higher education spending per student, falling from 9th in the nation in FY 2001 to 34th in FY 2004.

Uneven and missing connections in industry-university collaborations. Massachusetts is well known for how much of its technology base has emerged from its university, teaching hospital and federal research centers. This legacy points to the important role that research drivers play in generating research and technology leaders—the scientific originators, scientific workforce and entrepreneurial managers—needed to form and lead new companies. But that culture of collaboration has broken down. As one executive put it in an earlier Mass Insight report, "Not too long ago, the Massachusetts economy was dominated by a half dozen or so top players, such as Raytheon, Wang, Data General and Digital. You could get together a dozen people in an informal way to plan strategies and programs. Then the economy crashed, and the new economy is filled with hundreds of smaller, faster-growing players. Now you have to bring a hundred people to the table."

This study finds mounting evidence that the connections between industry and university are not what they could be. The sense that emerges from discussions with

A particular contrast for Massachusetts is the ongoing development of the University of California system.

Over the last twenty-five years, the once-modest University of California campuses at San Francisco and San Diego have been transformed into research powerhouses, attracting and spinning off new industries and companies.

While UMass as a system has experienced above-average growth in research and development in recent years, its leading campuses still seriously trail aspirant peers such as Berkeley for Amherst and UCSF for Worcester, and have not yet reached the level of critical mass necessary to have the desired economic impact on their regions.

The shortcomings of the UMass campuses compared to University of California campuses are not surprising when one considers that California allocates $18,000 per student at UC, Berkeley compared to $10,000 that Massachusetts allocates per student at UMass Amherst.

industry and university officials is that the potential that exists in Massachusetts for broader, more exciting collaborations and strategic alliances remains untapped.

- Massachusetts is not keeping pace with leading competitor states in the growth of industry support for university research and development. In particular, California, Texas and North Carolina have moved ahead of Massachusetts, realizing much stronger growth in industry research funding for universities from 1994 to 2001.
- Input gathered for this project from 74 technology companies in Massachusetts, of which nearly 85 percent have an active research and development program, reveals that Massachusetts can do more in promoting collaborations. Of the companies engaged in research activities, only slightly more than half have active research-related collaborations with universities, involving sponsored research, technology licensing, technical problem solving or use of facilities. Of those who do have university relationships, they typically involve both Massachusetts and non-Massachusetts universities. A smaller sample of these firms—51 out of the 74—indicate that they are as likely to go out-of-state as in-state for the broad range of industry-university research-related collaborations, including sponsored research, technology licensing, technical problem-solving, use of facilities and equipment and workforce training.

Input gathered for this project from 74 technology companies in Massachusetts reveals that Massachusetts can do more in promoting collaborations.

Meeting the New Terms of Competition for Innovation

At the same time that Massachusetts is showing signs of vulnerabilities in its research base, it must face the changing terms of competition for innovation, including:

- **A rise in "open" innovation,** where companies move away from a reliance on internal R&D labs, instead partnering with small and large companies, as well university and federal research centers, as their sources of innovation.
- **Technology convergence—innovation across disciplines.** The changing nature of research, reflected in the growing importance of technology convergence. Increasingly, the most important scientific questions and advances require multi-disciplinary research teams often across institutions.

The implication of these two shifts—toward open sources of innovation and multi-disciplinary research—is that states and regions that promote a broader culture of collaboration and specific strategic alliances in targeted technology areas will be big winners, supporting not only local industries, but attracting major outside investment.

In fact, states and regions across the nation are mounting efforts to master these new terms of competition. Not only are states investing significant funds— today reaching a half billion dollars and more in funding over a multi-year period—they are working smarter.

States are investing to establish a critical mass of excellence across their research drivers, particularly in their public university system, and are advancing integrated, multi-disciplinary, multi-institutional initiatives poised to capture the economic benefits of their growing research base. Examples include North Carolina with its Biotech Center, founded in the 1980s at the start of the biotech era. This center has helped to grow the state's biotech base by combining research, product development and industry support. Another long-standing example is Pennsylvania's Ben Franklin Partnership. Its regional centers began supporting industry-university research partnerships twenty years ago, then moved to supporting technology industry development with early stage capital and have now added strategic greenhouses for industry-university consortiums in specific areas of technology focus. In the past ten years, the Ben Franklin Program has led to a documented generation of 35,579 "job years" associated with companies it assisted and generated $400 million in additional state tax revenues, significantly more than the cost of the program. A more recent example is the Georgia Research Alliance, which has targeted the recruitment of eminent professors and major new research facilities, both efforts guided by industry input. The alliance has also focused on supporting and recruiting early stage companies associated with its new corps of star faculty. The results are that $300 million in state funding during the 1990s has generated $900 million in additional research funding, spurring 75 start-ups with 2,000 high tech jobs by early 2002.

It is only by working smarter with their science and technology base that states can garner competitive advantage, particularly in the face of increasing international competition. Chairman and CEO of IBM, Samuel Palmisano, explains the challenge: "A key determinant of growth is innovation. Where, how and why innovation happens is changing. If the U.S. wants its fair share of new jobs and economic growth, it must take the steps necessary to continue offering the most fertile, attractive environments for innovation in the world."[1]

It is only by working smarter with their science and technology base that states can garner competitive advantage, particularly in the face of increasing international competition.

Massachusetts is only beginning to advance investments in science and technology. Over the past twenty years, Massachusetts has not significantly invested in science and technology initiatives, relying instead on ad hoc relationships, market forces and the state's entrepreneurial culture to fuel its technology-based economy. But this is not sufficient to keep Massachusetts' leadership position. As Ray Stata, chairman of Analog Devices and a founding member of the Mass High Tech Council, explains: "In an environment where other states are aggressively competing for high tech businesses and jobs, it is irresponsible for Massachusetts state government to leave the future of its leading and most promising sectors to chance."

An Agenda for the Future

2004 will herald the first significant investment in Massachusetts broad science and technology capacities in many years. But it is only a start.

Massachusetts must meet three serious economic challenges:

- Maintain its historic position of educational and R&D leadership, as a magnet for talent and driver for economic growth and job creation.
- Increase the direct impact of the state's R&D base on its economy, competing for downstream jobs that benefit from locating near R&D operations.
- Harness the state's R&D engine to drive economic growth in regions where there is room and need for growth.

1. Samuel J. Palmisano, "How the U.S. Can Keep Its Innovation Edge," *BusinessWeek*, November 17, 2003, page 34

Four Key Economic Drivers

This technology road map for strategic alliances suggests four economic drivers on which Massachusetts can build technology leadership that will effectively drive economic growth and opportunity:

1. Leverage Massachusetts' breadth and strengths by promoting multi-institutional strategic initiatives that reach not only across universities, but also among universities, industry and government.

This report suggests a set of such initiatives which, taken together, represent a portfolio approach to investment in the innovation that is creating new industries and firms. The list is neither prescriptive nor exhaustive. Instead, its intent is to jump-start a deeper analysis of these and other ideas, at least some of which would then be implemented collaboratively.

2. Improve the translation of research strengths into products and industry development.

This report suggests a set of technology development connecting activities that can both smooth and accelerate this process. These include life sciences commercialization and bioprocessing efforts, a statewide medical devices network, a test-bed for information and communications technology industries and a network of regional product development centers that can tap university expertise to enable and promote high value-added manufacturing.

3. Strengthen the state's overall position in research and promote regional economic development by investing strategically in the University of Massachusetts.

A strategic, targeted investment program to build the UMass system into a top-tier technology university will help to reverse Massachusetts' brain drain and declining market share in research activity, help to steer technology development to outlying region's of the state where the overwhelming majority of UMass campuses are based and be an important tool for promoting collaborations with industry and private universities in Massachusetts. The lion's share of the growth in research funding at UMass will come from non-state support, but the key is to have a long-term, predictable commitment by the state to invest in growing UMass. Moreover, it is important to recognize that 85 percent of in-state UMass graduates choose to stay and build their careers in Massachusetts.

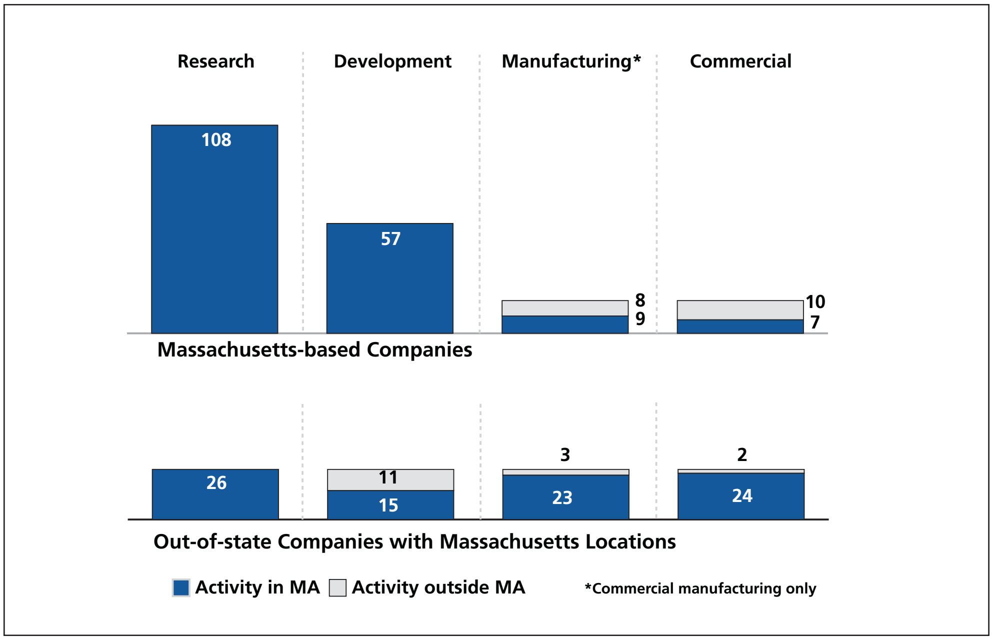
4. Develop a broader compact to ensure coordination across state and quasi-public agencies and communications across key stakeholders.

A key risk for Massachusetts as it advances in its future investments in strategic alliances, technology connections and building the capacity of UMass is that these investments will be managed as isolated activities, more piecemeal than part of a broader change in how Massachusetts collaborates. What is needed are mechanisms to ensure coordination and collaboration—not a new independent organization. These new mechanisms should ensure coordination among the many state public and quasi-public agencies involved in science and technology initiatives, as well as advance a new compact which brings together Massachusetts' industry, public and private universities, teaching hospitals and government to set overall goals, identify specific opportunities and help measure progress of the state's science and technology initiatives.

Choosing to Lead

Will Massachusetts capture the full range of new economy jobs?

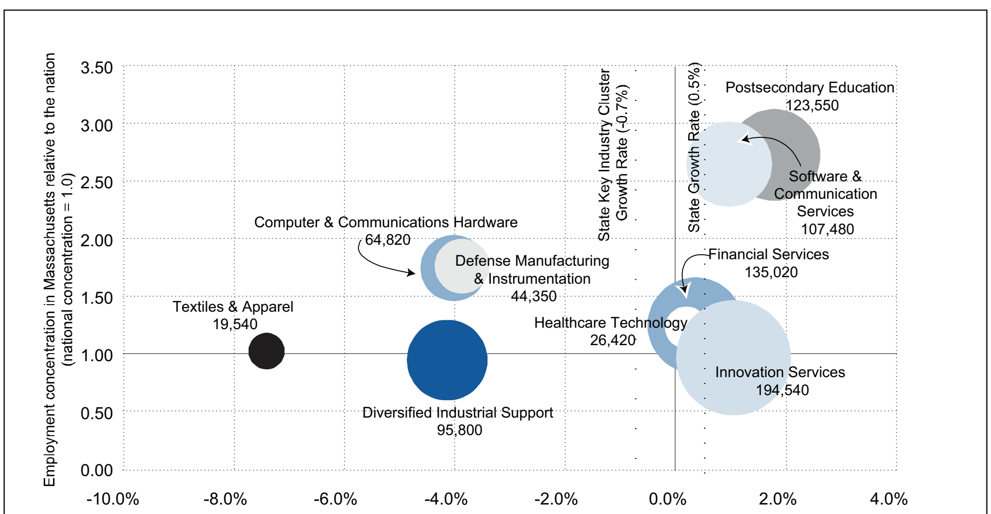
Biotech Activities Located in Massachusetts by Stage of Value Chain



Source: Massachusetts Biotechnology Council Survey 2002, BCG analysis

As Massachusetts' biotech firms mature, will we compete for production facilities here?

Portfolio of nine key industry clusters by employment concentration and growth, Massachusetts, 1998-2002



Note: Numeral below name of industry cluster is 2002 total employment

Source: Economy.com

Will Massachusetts be able to reverse the decline in defense manufacturing and telecommunications jobs as new technologies move into production?

The Massachusetts New Economy Agenda: Recommendations and Priorities

Summary and related priorities

The following is a summary of the concerns raised and the recommendations made in this report. Related priorities include major issues that emerged from the research conducted and/or have been identified in previous reports by Mass Insight and other research organizations in Massachusetts.

Collaboration and coordination starts at the top. Public and private sector leaders from the Science and Technology Initiative should establish a formal compact to shape new initiatives based on the concerns and recommendations below. Specifically, two steps are needed:

1. A **coordinated state strategy**, led by the Governor, to invest the new funds provided to the Massachusetts Technology Collaborative and Mass Development through the Economic Stimulus package, and

2. An **ongoing forum** for public and private leaders of the Science and Technology Initiative to meet with state leaders to shape priorities, establish goals and track progress.

Concerns	Recommendations	Related priorities for follow-up
1.R&D market share loss	• Multi-institution strategic alliances	• Insuring the future of Hanscom and Natick • Massachusetts advocacy for increased federal research funding
2. Losing the competition for talent	• Multi-institution strategic alliances • Development of UMass	• Coordinated regional strategies for community colleges and technical workforce development • Housing, particularly for younger professionals and technicians • K-12 math and science initiatives
3. Underinvestment in public research university	• Development of UMass	• Procurement reform, especially facilities construction • State higher education funding formulas and incentives
4. Weak history of collaborations	• Multi-institution strategic alliances • Technology-connecting activities	• Intellectual property policies
5. Changing nature of R&D	• Multi-institution strategic alliances • Technology-connecting activities	• Cluster-based strategy to capture R&D linked advanced manufacturing
6. New models of competition	• Multi-institution strategic alliances • Technology-connecting activities	• Siting and permitting for research production facilities
7. Inability to capture downstream jobs	• Development of UMass • Technology-connecting activities	• Siting and permitting for research production facilities • Regional infrastructure • Workforce development • K-12 math and science initiatives

The Massachusetts Technology Road Map and
Strategic Alliances Study

Case Statement and
Core Technology Audit

The Vulnerability of Massachusetts' Technology Position: Internal Challenges

What gives leaders from across technology sectors in the state great concern are signs of vulnerability, where Massachusetts is losing its competitive advantages. This is particularly found in recent trends in talent generation and retention, as well as university, federal, and industry research activity—key foundations for technology innovation.

Unlike an economic recession, where there are immediate job losses and business closings, the erosion of Massachusetts' competitive technology position will slowly erode the economic vitality of the Commonwealth. It will be hard to see its full impact until it is too late to recover. As William Terry, vice president of corporate sponsored research and licensing at Partners HealthCare System, explains, "What we see today is just a symptom and the disease will become manifest 10 or 20 years in the future, unless we start the preventative measures now."

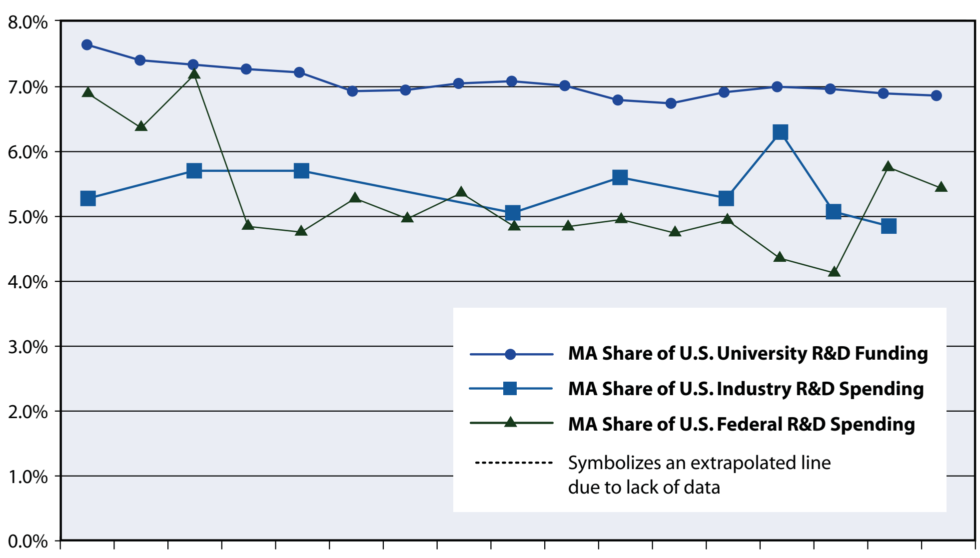
Since the mid-1980s, Massachusetts has been losing market share in research activity.

The enormous advantage Massachusetts has enjoyed in having a leading research base is in decline, currently below the levels of the mid-1980s. This is true whether one considers industry, university or federal research activity.

These three drivers of research activity provide a good way to understand the dynamics of research in Massachusetts *(see Figure 1)*. Industry is the largest performer of research activity both in Massachusetts and across the nation. Industry research is largely self-funded, but is also a major recipient of federal funding for defense and small business innovation research grants. Typically, industry research tends to be more

Massachusetts' share of R&D is lower today than in the mid-1980s.

Figure 1: Massachusetts' share of U.S. Federal, University, and Industrial R&D Spending, FY 1985-2001



Key Points on Massachusetts' Internal Challenges

- Massachusetts is losing market share in research and development activities.
- The possible closure of major military facilities at Hanscom Air Force Base and Natick Army Labs is a threat to the research and development base.
- Massachusetts is constrained in technology innovation by the small size of its public university research base, reflecting a pattern of underinvestment.
- Massachusetts is no longer a clear winner in the competition for talent.

focused on applied research. In contrast, university research is more focused on basic research and thus is a good complement to industry research activity. The largest funding support for university research comes from the federal government, but industry, foundations and state government are also important sources of funding. Federal research activity covers many different performers from industry, universities and its own dedicated research centers and facilities, such as Lincoln Labs, MITRE, Hanscom Air Force Base and Natick Army Research Labs.

University Research — A steady decline in market share.

Massachusetts has fallen steadily since the mid-1980s in its share of all university research and development in the U.S., from 7.6 percent in 1985 to 6.9 percent in 2001. Key competitor states, on the other hand, are not falling behind in university research. California has significantly increased its expenditures in university R&D in the 1990s and now stands slightly above its market share of 13.0 percent in 1985 with 13.5 percent in 2001. North Carolina has generally recorded steady increases in its market share in university research, from 2.7 percent in 1985 to 3.5 percent in 2001.

Federal Research — A fall-off since the end of the Cold War and a failure to fully leverage the run-up in funding at NIH.

Similarly, the share of federal research funding awarded to Massachusetts—which supports universities, teaching hospitals, industry and federal research labs, and research facilities in the state—has continued to decline, from nearly seven percent in 1985 to 5.5 percent in 2001. The share of federal research activity in Massachusetts took a sharp nose-dive in the late 1980s with the end of the Cold War and generally continued to fall throughout the 1990s—even with sharp increases nationally in federal biomedical research. With the recent increase in defense spending, this fall-off in the share of federal research has reversed, but remains at levels well below the market share of the mid-1980s.

A detailed look at more recent trends by type of performer points to many troubling signs even as overall Massachusetts federal research activity has rebounded with the gains in defense research activity *(see Table 1 on the following page)*. The Massachusetts Technology Collaborative in its Winter 2004 "R&D Funding Scorecard: Federal Investments and the Massachusetts Innovation Economy" points to continued declining market share of federal research spending for federal research facilities (i.e., Hanscom Air Force and Natick Army bases), universities and non-profits:

- **Federal research facilities under threat.** Through FY 2000, Department of Defense (DoD) installations at Natick and Hanscom continued to see decreasing funding, potentially making them more vulnerable to closure during the next round of Base Realignment and Closure (BRAC). However, FY 2001 data indicates strong growth in funding from DoD for its intramural research in Massachusetts, possibly in activities related to homeland security. Loss of either facility would have a ripple effect throughout the state's R&D community and innovation economy, one that is much larger than reflected in the intramural funding numbers.
- **Universities and non-profits not keeping pace.** The low growth in federal funding for the Commonwealth's universities, colleges and non-profits is particularly disturbing. Some of this may be the result of demographics—enrollment in both the state's public and private universities has been largely static or, in some cases, declining. However, other low enrollment growth states, such as Connecticut or

Warning Signs

Mass Tech Collaborative in its Winter 2004 *R&D Funding Scorecard: Federal Investments and the Massachusetts Innovation Economy*, sounds the alarm: "The fact that funding for [federal] research in most performing sectors is growing faster in other states has many obvious and disturbing implications…The relatively high growth rates in the other leading technology states suggests that we are in danger of losing what has generally been acknowledged as one of the key competitive strengths of Massachusetts—our reputation as one of the best centers of research and higher education in the world. This has important implications for the state's ability to attract the best talent and to create the leading edge technology to fuel the Innovation Economy."

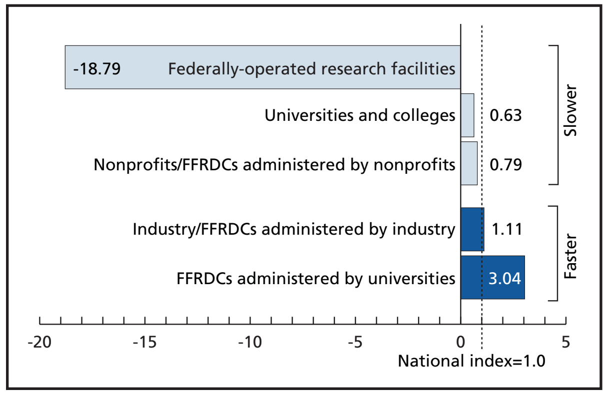
New York, have performed much better in obtaining federal R&D funding. Massachusetts' market share of federal R&D funding to universities and colleges has dropped from over 11.5 percent in 1982 to under six percent in FY 2000. This is the largest loss of market share among the 50 states and the District of Columbia.

Massachusetts' non-profits rank Number 1 in market share, but they have been slowly losing market share during much of the past decade. California, ranked number 2, is growing 25 percent faster than Massachusetts. Number 3 ranked New York is growing almost four times as fast as Massachusetts.

- **Massachusetts falling behind in NIH funding growth.** What is surprising is that universities and non-profits in Massachusetts have failed to outpace the nation, considering that the main source of their federal research spending comes from the National Institutes of Health under the Department of Health and Human Services. While HHS spending rose nationally by 80 percent from FY 1996 to FY 2001, the Mass Tech Collaborative reports that Massachusetts research funding from HHS rose only 75 percent—and the Growth Index for all major performers in HHS research was below the national average for universities, for non-profits and for industry (a growth rate of 1.0 is the national average and less than 1.0 means lower growth than the nation).

Massachusetts recorded a mixed performance in the growth rate of federal R&D, slipping in federal R&D for federal facilities, universities and non-profits.

Table 1: Growth Index for Massachusetts research facilities—federal research activity, FY 1995 to FY 2000



Source: National Science Foundation, calculations by MassTech Collaborative

Note: The Growth Index is the ratio of the growth for Massachusetts to that of the nation for the performer during the 1995 to 2000 period.

A Growth Index greater than 1.00 indicates that federal research activity during that period grew faster than the national rate. A Growth Index less than 1.00 indicates slower growth than the national rate. A negative Growth Index indicates a decline in research activity during that period.

The only bright spots have been in federal funding performed by industry and federally-sponsored research centers (FFRDCs) administered by universities, which have both benefited from the rise in defense research spending in recent years.

Industry R&D – More recent warning signs of decline, including for small, emerging, innovative companies.

Industry research and development activity has sharply declined in the late 1990s with the dot.com bust and is at its lowest levels of national market share. Over the late 1980s and through the 1990s, industry research and development fared better than university or federal research activities, staying generally flat until taking off during the dot.com boom. The spike in dot.com research activity has been followed by a major bust, with industry research and development now recording two straight years of decline for 1999 and 2000. By the end of 2000, Massachusetts' share of total industry research and development stood at 4.9 percent—its lowest level of the 1985 to 2000 period—compared to 5.3 percent in 1985.

Of particular concern for Massachusetts is how the state's base of small, emerging, innovative firms is doing in research with a fall-off in venture financing and slow growth in SBIR awards. These small, emerging, innovative firms represent the farm team of future industry leaders for Massachusetts. One key concern is that venture capital—a key funding source for industry R&D—is well off. In 2002, venture investments in Massachusetts firms were down 50 percent from 2001, receiving only $2.4 billion in 2002 compared to $4.8 billion in 2001. Fortunately, Massachusetts is holding on to its market share as a center of venture capital financing.

Massachusetts is not doing as well in another key source of research funding for small innovative firms, the Federal Small Business Innovation Research (SBIR) program.

These SBIR awards provide an important source of funding for new product development for emerging technology-based companies. Particularly in these down times for venture capital financing, SBIR represents an important source of research funding for small, emerging, innovative firms. Massachusetts, as would be expected, has been a leading state in receiving SBIR awards. But Massachusetts firms are not keeping pace with the national growth in SBIR funding. The Mass Tech Collaborative reports that overall SBIR grants rose 27 percent nationally, but only 13 percent in Massachusetts from FY 1996 to FY 2001. Massachusetts has particularly lagged in NIH SBIRs, from garnering 25 percent of all NIH SBIR funds in FY 1996 to 16 percent in FY 2001.[2]

In spite of above-average R&D growth rates in recent years, all of the UMass campuses combined would rank as only the 42nd largest research university in the nation today. No single UMass campus ranks higher than 94th in the nation among all research universities.

Massachusetts is constrained by underinvestment by the state in the research efforts of its public university system, UMass.

In university and federal research activity, one key factor holding Massachusetts back is the small size of the public university research effort found at the University of Massachusetts (UMass). Massachusetts' public university research base is less than half the size of those found in New York, North Carolina and Pennsylvania. UMass particularly pales in comparison to the University of California. All of the UMass campuses added together stand behind the research level found individually at the campuses of UCLA, UC Berkeley, UC San Diego and UC San Francisco. All the UMass campuses combined would rank as only the 42nd largest research university in the nation today.

While UMass has been growing strongly in research, its performance as a research driver stands well below public universities in other states, such as California, New York, North Carolina and Pennsylvania, that have major private research universities.

Given UMass's relatively successful record in R&D growth with a limited state investment—out-pacing the national and state averages in recent years and successfully competing for a number of nationally competitive centers in just the past year—there is good reason to believe that strategic investments in UMass can help address the declining market share of university research in Massachusetts. If the level of funding to UMass were closer to the average size of its state peers of New York, North Carolina and Pennsylvania, say approximately $600 to $800 million, then today Massachusetts' market share of university research would be higher than in 1985. Since most university research is supported by federal funding, this would also be a key boost to the state's lagging share of federal research activity. A typical rule of thumb is that a one dollar investment by the state in supporting research activity will result in at least a three dollar return in federal and other non-state sources of research support. So, most of the funding to get UMass to a $600 to $800 million research level will come from non-state sources.

UMass is well below the size of key competitor states in research activities and share of overall state university research, but has grown substantially in recent years, outpacing many of its key competitor states.

Table 2: Comparison of public university research activities – Massachusetts versus key competitor states

State	Size of Public University Research Budget, 2001	Percent of Total University R&D in State, 2001	Percent of Growth Rate, 1995-2001
California	$3,299	74.6	69.2
Massachusetts	$251	11.2	59.7
New York	$663	58.3	53.5
Pennsylvania	$870	51.6	51.1
North Carolina	$588	23.7	32.6

Source: National Science Foundation, calculations by Battelle
Note: Absolute dollars were intentionally used rather than per capita for the size of the public university research budget to reflect critical mass of activity.

What appears to be holding UMass back is wavering overall state support and a particularly limited state-supported capital budget to expand research-related facilities. Massachusetts has the distinction of having the highest percentage decrease in state higher-education appropriations of all fifty states, not just for the current fiscal year, but over the past two years. The depth of the cuts in state funding for higher education in Massachusetts over the past two years—a 23 percent reduc-

2. See Mass Tech Collaborative, The R&D Funding Scorecard: Federal Investments and the Massachusetts Innovation Economy, Winter 2004.

tion—has resulted in Massachusetts being the only state in the nation to record a decline in state funding of higher education over the past ten years. While Massachusetts decreased its spending on higher education by 5.3 percent from FY 1994 to FY 2004, California increased its spending by 91.8 percent, North Carolina increased by 50.1 percent, Pennsylvania by 27.7 percent and New York increased by 21.6 percent *(see Table 2)*.

State appropriations to UMass research campuses significantly lag competitors.

Table 3: State appropriations (per FTE student) to selected research campuses

Campus	State Appropriation (milions)	Student FTE	Appropriation per FTE
UCal Berkeley	$510.9	31,458	$16,242
UNC Chapel Hill	$368.0	23,330	$15,775
UCONN	$288.0	18,743	$15,365
UCal San Diego	$322.5	22,883	$14,095
SUNY Buffalo	$322.2	23,035	$13,989
UMass Amherst	$212.5	21,447	$9,907

Source: Data compiled by University of Massachusetts from state university sources & IPEDS. All data is FY2003 with the exception of SUNY Buffalo which is FY2002.

When one considers Massachusetts' funding for higher education per student, what is striking is the significant swings and lack of consistency in state financial support. It appears that Massachusetts looks to public higher education to cut first in difficult fiscal times, creating uncertainties and lack of long term commitment. The significant swings over the course of a recession are reflected in Massachusetts' ranking in state appropriations for public higher education per student (full time equivalent). In FY 1990, Massachusetts per public higher education student support was eighth, but by the end of the recession in FY 1992 it had dropped to 35th in the nation. Similarly during the recent recession, Massachusetts was ninth in the nation in public higher education support on a per student basis in FY 2001, and by FY 2004 Massachusetts had fallen to 34th.

Massachusetts has the distinction of being the only state to record a decrease in state funding for higher education over the past ten years.

By comparison, the nation as a whole and key comparison states have not had enormous swings, with per student spending for public higher education falling less. In the most recent recession, North Carolina and New York have actually increased their per student spending on public higher education from FY 2001 to FY 2004, while the U.S. average is much smaller than the reduction in Massachusetts *(see Table 4)*.

In the area of capital spending, the lack of funding for UMass is particularly striking. Outside of maintenance payments, new capital appropriations to UMass are slim. In FY 2001, it amounted to just $23 million, FY 2002 $47 million and FY 2003 $25 million. As a point of comparison, neighboring Connecticut is nearing completion of a $1 billion UConn 2000 capital investment program and a $1.3 billion UConn 21st Century capital investment program will be starting up in FY 2005. The UMass system maintains comparisons with other "peer" systems and finds that for UMass, state support for facilities is $689 per student compared to $1,291 at peer university systems, including $1,320 at the University of California. A tried and true key to building a premier research university is having an aggressive facility construction program.

Massachusetts is cutting support today for public higher education while its competitors continue to invest, and in the past recession, Massachusetts cut public higher education deeper than other states.

Table 4: Changes in per student higher education spending over recession periods – FY 1990 to FY 1992 and FY 2001 to FY 2004

State	Change from FY 1990 to FY 1992	Change from FY 2001 to FY 2004
Massachusetts	-$1,724	-$2133
California	-$368	-$1178
New York	-$438	+$392
North Carolina	-$640	+$121
Pennsylvania	+$195	-$360
U.S. Average	**-$139**	**-$275**

Source: Grapevine for State Appropriations and IPEDS for full time equivalent students.

Despite having significant means, Massachusetts has failed to make the effort to have a leading public university system. This lack of commitment is further reflected by how much Massachusetts spends for public higher education compared to its capacity. A key measure of capacity is the level of state spending per $1,000 of state income. Massachusetts ranks among the lowest states in the nation at 49th, just more than half of what the average state spends and two and a half times less than those states ranked in the top ten. Even in per capita terms, Massachusetts is well behind other states—with $158 capita, ranking it 48th in the nation.

Massachusetts is no longer a clear winner in the competition for talent.

Another area of mounting concern is that Massachusetts is beginning to show signs that it is falling behind other states in the battle to retain its most significant technology product—its higher education graduates. Ultimately, both the creation of great research and the translation of the research into products and services are done by technically educated, talented people. Higher education graduates—from the associate through the PhD levels—being employed and starting firms carry innovation with them, making them the best mechanism for technology transfer.

A recent Census study on the migration patterns of a specific population group that is central to the competition for talent—those who are 25 to 39 years old, single and college-educated found striking evidence that Massachusetts is indeed losing ground.[3]

At a state level, Massachusetts was a net loser of young, single and college-educated residents from 1995 to 2000—this at a time of booming state economic growth when the demand for such residents would be at a peak. Overall, Massachusetts lost 1,062 of these highly prized residents, a negative migration rate of half of one percent. By comparison, a mix of key technology competitors—such as California, North Carolina, and Texas—and a rising set of future economic competitors—Colorado, Georgia, Washington, and Florida—well outpaced Massachusetts *(see Table 5)*.

Even the Greater Boston metropolitan area did not fare well in comparison to the competition. While the Greater Boston region was a net gainer of 4,736 residents among young, single and college-educated residents, a positive migration rate of 2.19 percent, it falls short of other key metropolitan areas. Boston was not among the top twenty metropolitan areas in the rate of net migration—it was actually not even close. These top 20 regions had net migration rates of roughly 15 percent and higher. Included among the top 20 were San Francisco, Seattle, Atlanta, Denver, and Phoenix. But Boston also lagged behind New York, Los Angeles, Chicago, Washington-Baltimore, Minneapolis and San Diego in net migration rates of young, single and college-educated residents *(see Table 6)*.

Massachusetts lost the talent competition for 25- to 39-year-old, single, college-educated people, and Boston fell well behind other leading metropolitan regions.

Table 5: Top ten states and Massachusetts in domestic migration of people who were young, single and college educated, 1995 to 2000

State	Net Migration	
	Number	Percent
Arizona	9,264	110.0
Nevada	6,788	28.2
Colorado	17,862	15.8
Georgia	24,667	15.2
Oregon	6,356	10.4
Washington	11,669	9.7
California	73,037	9.3
North Carolina	7,219	5.2
Texas	16,813	4.9
Florida	10,454	4.0
Massachusetts	**-1,062**	**-0.5**

Table 6: Boston compared to leading metropolitan regions in domestic migration of people who were young, single and college educated, 1995 to 2000

Greater Metro Area	Net Migration	
	Number	Percent
Atlanta	31,887	28.2
Denver	19,679	26.4
Phoenix	13,768	25.1
San Francisco	49,468	19.9
Seattle	17,554	19.5
Minneapolis	10,249	12.4
Washington-Balt.	25,469	10.2
San Diego	7,083	10.0
Los Angeles	32,998	9.2
Chicago	18,750	7.3
New York City	25,131	3.7
Boston	**4,736**	**2.2**

Source: U.S. Census Bureau, Migration of the Young, Single and College Educated: 1995 to 2000, Special Report, November 2003
Note: Greater Metro areas reflect the consolidated metro region.

3. U.S. Census Bureau, Migration of the Young, Single and College Educated: 1995 to 2000, November 2003.

The Vulnerability of Massachusetts' Technology Position: External Challenges

One does not need to look far to understand why Massachusetts is vulnerable. The world is rapidly changing and a new competitive landscape of global activities in science and technology is emerging, which Massachusetts must address to maintain its leadership position. As the Chairman and CEO of IBM, Samuel Palmisano, explains the challenge to the U.S. broadly: "A key determinant of growth is innovation. Where, how and why innovation happens is changing. If the U.S. wants its fair share of new jobs and economic growth, it must take the steps necessary to continue offering the most fertile, attractive environments for innovation in the world."[4]

In the struggle for preeminence in science and technology, other states are actively at work to master the terms of this new competition, while Massachusetts clings to its old ways of doing business. But the situation for Massachusetts is even more troubling, as a chasm has arisen in Massachusetts between its university base of research and its technology companies in terms of connectivity and collaboration.

In the decades from the post-war through the early 1980s, Massachusetts was held up as a national and international model for what collaboration could achieve. Effective collaborations such as the "2 percent" solution of the 1970s that built up university engineering research and education capacity in the state with support from industry and state government were widely heralded. But that culture of collaboration broke down. As one executive put it, "Not too long ago, the Massachusetts economy was dominated by a half dozen or so top players, such as Raytheon, Wang, Data General and Digital. You could get together a dozen people in an informal way to plan strategies and programs. Then the economy crashed, and the new economy is filled with hundreds of smaller, faster-growing players. Now you have to bring a hundred people to the table."

Massachusetts must address its own changing situation if it is to meet the challenges of today's evolving terms of competition, including:

- The emergence of a new paradigm for research;
- New models for state technology development to build research capabilities and connect to economic drivers;
- The rise of international competitors; and
- The ultimate competition—generating, attracting and retaining talent.

Key shifts in how research and development is conducted demand new types of strategic alliances to gain competitive advantages.

Massachusetts must come to terms with a changing world in how industry is pursuing R&D and innovation. Largely gone from the scene is the predictable path of having companies rely primarily on internal research labs for innovative ideas. In its place, a more dynamic interaction across companies, universities and federal laboratories is unfolding.

Key Points on Massachusetts' External Challenges

- The research paradigm is changing with the rise of open innovation and technology convergence.
- New models for state technology development are being advanced that better link the research base to economic development.
- International competition is growing.
- Ultimate competition is for talent to support research, product development and manufacturing.

4. Samuel J. Palmisano, "How the U.S. Can Keep Its Innovative Edge," Business Week, November 17, 2003, page 34

Open innovation — networks of smaller companies and collaborations replace the Bell Labs of the past.

Today, companies such as Merck, Xerox, Procter & Gamble, BASF and Dow Chemical are seeking help from outside their organizations in addressing key research problems. A growing phenomenon is having companies open research centers next to major research universities, like Intel, Novartis and Pfizer have done. While many of these research centers are smaller "lablets," many can be quite major, such as the Novartis research lab opening in Boston that will have 1,000 scientists in 750,000 square feet of laboratory space.

With the decline of major corporate research laboratories and a focus by corporations on diversifying the sources of innovation from which they draw, there is a rising need for strategic alliances across universities and industry to fill the demand for innovation. The absence of major corporate research labs to move technology forward is also creating pressure for universities to further develop their research discoveries in order for them to be commercially viable and sufficiently developed for industry use and application.

States and regions that can promote a broader culture of collaboration across their university and industry sectors will be big winners in this changing paradigm, supporting not only local industries, but attracting major outside investment to their states. It will also become important for states to ensure that there are sources of research expertise and capacity to support the range of research needs within and across the state's specific economic clusters.

And more than ever, states with substantial research bases run the risk of having their ideas developed outside of their state if more active means for capturing broader aspects of product development and advanced manufacturing are not sufficiently addressed.

Multi-disciplinary collaborations are producing the next wave of innovation and this play to Massachusetts' strength across disciplines.

At the same time, the need for technology convergence to address key research problems is defining a new path for advancing scientific research and innovation.

A second key shift is the changing nature of research itself. More and more, the most important scientific questions and advances require interdisciplinary research teams, often across multiple institutions. Again, this calls for working in new ways through strategic alliances, often among various universities, teaching hospitals and other basic research organizations.

As a recent article in the *Chronicle of Higher Education* notes: "[interdisciplinary] partnerships are proliferating in academe—and slowly changing the face of science—because they offer the best hope for answering some of the thorniest research subjects including climate change, biodiversity and cancer."[5]

The challenge to the United States and leading states, such as Massachusetts, is not just the need to keep up the pace of investments in science and technology, but to learn to work smarter. Nanotechnology is a great example of an interdisciplinary technology. Nanotechnology brings together physicists, chemists, material scientists, electrical and chemical engineers and many other disciplines to address new methodologies, techniques and fabrication processes. Success in the biosciences depends as well upon

New Paradigm for Corporate R&D and Innovation is Emerging

"…a new R&D model is emerging, dubbed open innovation. Companies of all sizes are rounding up more partners, big and small, than ever before and they're casting wide research nets, snapping up work at diverse corporate, government and academic labs."

"Reinventing Corporate R&D," *BusinessWeek*, September 22, 2003

"A transition has been under way at many pharmaceutical companies for several years, but firms are now moving rapidly to search out mergers, forge collaborations with academic groups, strike deals with biotechnology companies, and establish outposts near hotbeds of university research."

Stephen S. Hall, "Revitalizing Drug Discovery," *MIT Technology Review*, October 2003

"Not long ago, internal R&D was viewed as a strategic asset and even a barrier to competitive entry in many industries…Rivals who sought to unseat these firms had to ante up their own resources and create their own labs, if they were to have any chance against these leaders. These days, the former industrial enterprises are finding remarkably strong competition from many newer companies. These newcomers—Intel, Microsoft, Sun, Oracle, Cisco, Genentech, Amgen, Genzyme—conduct little or no basic research on their own. Although they have been very innovative, these companies have innovated with the research discoveries of others."

Henry Chesbrough, "Open Innovation," *Harvard Business School Press*, 2003

5. Jeffrey Brainard, "U.S. Agencies Look to Interdisciplinary Science," Chronicle of Higher Education, June 14, 2002

integrating a variety of technologies to advance new discoveries, as Ernst & Young points out in its annual recap of the biotechnology field:

"From agriculture to fine chemicals, from drug discovery to health, companies are migrating and integrating their scientific approaches and business aspirations to create broad platforms for new products and markets. Fueled by—and contributing to—developments in information technology and nanotechnology, these hybrid markets are true bellwethers of the information age, generating enormous quantities of information at multiple scales of time and space."[6] Few institutions, even at the level of a Harvard or an MIT, have the research strengths necessary to succeed in multi-disciplinary research. Increasingly it is only through institutional partnerships that multi-disciplinary research can succeed.

Thus, there is a need for new types of strategic relationships between universities and industry, among universities and even across departments within universities.

States are mastering new ways to compete using investments in science and technology to connect with industry growth.

Other states are learning from the success of Massachusetts. They have come to recognize that it is only through technology-related growth that they can ensure their own future economic prosperity. A study by the Milken Institute, a private, non-profit research organization, put this advantage of technology innovation into measurable economic terms. In evaluating the economic growth across 315 regions in the U.S. over the 1975 to 1998 period, the Milken Institute found that 65 percent of the difference in economic success for regions is accounted for by the growth and presence of high technology industries. Moreover, Milken Institute found that research centers and institutes are "indisputably the most important factors in incubating high tech industries."[7]

States across the nation are making significant targeted investments to advance their science and technology base.

So it is not surprising that, even in the face of difficult economic and fiscal times, states across the nation are making significant targeted investments to advance their science and technology base. These efforts are found across a mix of states from technology leaders to emerging technology states, from major population states to smaller states and from states in all regions of the nation.

Not only are these competitors establishing critical mass across their research drivers, but they are advancing integrated, multi-disciplinary technology initiatives poised to capture the economic benefits of their growing research bases. For instance, North Carolina, in pursuing biotechnology, not only sponsored research funding through the North Carolina Biotech Center to a range of public and private research institutions, but as the research led to new discoveries with commercial potential, the North Carolina Biotech Center focused on supporting new company formation through early stages of product development. In addition, North Carolina also ensured that it was a magnet for broader technology anchors through the Research Triangle Park, which attracted major federal research organizations, including the National Institute of Environmental Health from NIH, as well as major corporate research labs. Another example is the Georgia Research Alliance, which invested over $300 million over the course of the 1990s in eminent scholars to help move Georgia Tech, University of Georgia and Emory University into national research prominence. At the same time, Georgia has focused on supporting and recruiting early stage companies associated with its new corps of star faculty, which in early 2002 numbered 75 startups, 2,000 high-tech jobs and $500 million in private capital attracted to those startups.

6. Brian Sager, Ernst & Young Life Sciences Strategy Consultant, "Strategic Drivers of Convergence," *Convergence: The Biotechnology Industry Report*, Millennium Edition, 2001, page 26

7. Milken Institute, America's High-Tech Economy, 1999

The best example of state science and technology programs is, arguably, the Pennsylvania Ben Franklin Partnership Centers, found across the state. The Centers began by supporting industry-university research partnerships, then moved to supporting technology industry development with early stage capital and are now advancing strategic greenhouses for industry-university partnership in specific areas of technology focus. In the past ten years, Pennsylvania's Ben Franklin Partnership has generated 35,579 "job-years" associated with companies it assisted, which paid 28 percent higher than the average salary in the state, and $400 million in additional state tax revenues, significantly more than the cost of the program.

California also deserves particular attention. Similar to Massachusetts, California is an established technology-based economic powerhouse. Yet in the late 1980s and early 1990s, in the face of declining technology fortunes with the end of the Cold War and the economic recession, California faced some difficult choices. California built their public university research campuses, the University of California (UC) system in conjunction with industry partnership programs and focused efforts to establish leading research institutes involving multi-institutional partnerships.

The impact has been substantial. In San Diego, for example, the devastating losses in its defense/aviation technology sector in the early 1990s have been more than replaced by the growth of three technology sectors: communications, biotechnology and pharmaceuticals, and software and computer services. A key driver of this technology renewal in San Diego has been the emergence of the University California San Diego (UCSD), which 40 years ago did not exist as an operating institution and today stands as the sixth largest research university in the nation, on par with UCLA and UC Berkeley. It boasts five Nobel prize-winning faculty members, 60 members of the National Academy of Science, and over 80 endowed professorial chairs. But UCSD did far more than simply promote new research growth. It embraced its mission to promote regional development, and gave root to efforts such as its nationally known CONNECT program, that fosters the local entrepreneurial economy, involved in over 100 events a year. UCSD claims that over 40,000 jobs in the San Diego economy are now held by its graduates, many of them in the burgeoning number of high-tech companies that characterize the community. At least 41 San Diego-based communications and telecommunications companies were either founded by students or faculty, or spun off from firms with ties to UCSD, and its bioscience base grew from 11,000 workers employed in the biosciences in 1990 to approximately 23,000 today.

Major Investments by States through Recent Economic Recession

- **New York** invested $85 million towards a total $185 million Center of Excellence in Nanoelectronics in partnership with IBM and committed over $160 million in state funding for the creation of International SEMATECH North (ISMTN) a five year, $350 million partnership with industry; $100 million in state support for a $300 million total research effort with Tokyo Electron Limited on semi-conductor tool development and deployment; and $35 million in state funding to support the Interconnect Focus Center for Hyper-integration, funding innovative university research on nanoscale interconnect technology.
- **Texas** has invested for years in enhancing the state's R&D capacity both directly through targeted legislative appropriations (such as investments in University of Texas, Austin that helped attract Sematech and MCC) and indirectly through a large "Advanced Research and Technology Program" run by the Higher Education Coordinating Board. Most recently, the state funneled hundreds of millions of dollars to upgrading the capacity of smaller University of Texas campuses (especially UT Dallas and University of North Texas, but also the UT Health Science Centers in Houston and San Antonio) and expanding the mandate of the multi-institutional Texas Medical Center in Houston to encompass a commercially-oriented biotechnology research park.
- **Arizona** approved over $400 million for life science research facilities at its public research universities to go along with an over $100 million state-local-foundation and industry investment to establish the Translational Genomics Research Institute and attract the International Genomics Consortium to the Phoenix area. These investments are in addition to voter approved Proposition 301, which provided for a surcharge on the sales tax to fund K–12 and higher education, including supporting research activities.
- **Iowa** created a comprehensive "Iowa Values Fund" that is targeted to allocate $500 million over seven years to initiatives in information technology, life sciences and advanced manufacturing. The fund embraces upgrading R&D capacity, along with developing research parks throughout the public university system and complementary industry-attraction and assistance activities.
- **Indiana** enacted a $1.2 billion "Energize Indiana" program that calls for stabilization of the 21st Century Fund (an R&D capacity-building and partnership grant fund) at $75 million over the next biennium; about $300 million in new research buildings at the two main public universities; and $40 million for technology-oriented industrial parks statewide.
- **Florida** invested over $300 million to attract Scripps Laboratories to open a major world-class research center in West Palm Beach, Florida.

At the same time, international competition in science and technology is increasing.

The success of the U.S. in using its technology base to propel innovation and economic competitiveness is now being emulated by nations across the globe. While the United States remains the pre-eminent nation in science and technology, with each passing year its domination is shrinking.

Moreover, rapidly growing, developing nations, such as India and China, are proving to be strong competitors in R&D, and are beginning to attract significant direct investment in R&D, even from major U.S. firms such as Microsoft, GE, and IBM.

Assistant Secretary for Technology Policy, Bruce P. Mehlman, explains why:[8]

1. **Cost.** Research and other technical talent and facilities cost appreciably less in many areas of the world. Similarly, many foreign nations offer businesses and researchers significant financial incentives to locate R&D, technical services and manufacturing within their borders.
2. **People.** There are many highly talented researchers and technical workers among the more than six billion people on the planet who are not United States citizens, and some foreign nations such as China are now graduating more physical science and engineering students than the U.S. every year.
3. **Market access.** Many business leaders are attracted to the perceived market possibilities in rapidly developing nations such as China and India, with over 2.4 billion people between them. Proximity to customers is often essential to compete for service sector business. Other innovators believe they need to globalize their research efforts to overcome foreign government impediments to doing business or to ensure they can gain needed regulatory approvals in the future.
4. **Infrastructure.** Foreign governments are making their own investments in university and lab research facilities, transportation, energy and telecommunications to more effectively compete.
5. **Business climate.** A great number of top-tier innovative companies explain moves to Asia by pointing to its less burdensome taxation, regulation and litigation environments. These reflect both bottom-line and speed-to-market concerns, although many appropriately question whether nations lacking in freedom, robust intellectual property rights and thorough worker protections can sustain innovative leadership over a long period.
6. **Proximity to offshore manufacturing.** Semi-conductor experts, for example, indicate chip design work needs to happen close to manufacturing facilities. Thus the movement of manufacturing work portends the movement of the more innovative activities.

International Competition is on the Rise

Consider that back in 1970, the U.S. accounted for 70 percent of the total R&D spending of developed nations that were part of the 17-nation Organization for Economic Cooperation and Development (OECD). By 2001, we stood at 44 percent.

Bruce P. Mehlman, Assistant Secretary for Technology Policy, U.S. Department of Commerce

"The innovative capacity of OECD countries has converged substantially over the last quarter century. Although the United States and Switzerland maintain their top-tier positions across three decades, the relative advantage of these leaders has declined…Our study also shows that new centers of innovative activity are emerging outside the OECD. Singapore, Taiwan, South Korea and Israel have made substantial investments in upgrading their innovative capacities over the past decade and achieved large increases in patenting."

Michael E. Porter and Scott Stern, *Innovation: Location Matters*, MIT Sloan Management Review, Summer 2001, pages 32 and 34

8. Remarks by Bruce P. Mehlman, Assistant Secretary for Technology Policy, U.S. Department of Commerce, "21st Century Policy Challenges for American Innovation Leadership," Fall 2003

The ultimate competition is for talent.

In the face of this stiff competition, what will enable Massachusetts to stand out as a leader in technology innovation? How can Massachusetts be a leading place not just for research discoveries, but a place that can translate those scientific advances into new products and new industries of the future?

More and more it comes down to having a specialized concentration of talent—from PhDs to highly trained technicians—in key cluster areas. As the National Governors' Association 2002 report on State Leadership in the Global Economy, prepared in collaboration with the industry-led Council on Competitiveness, points out:

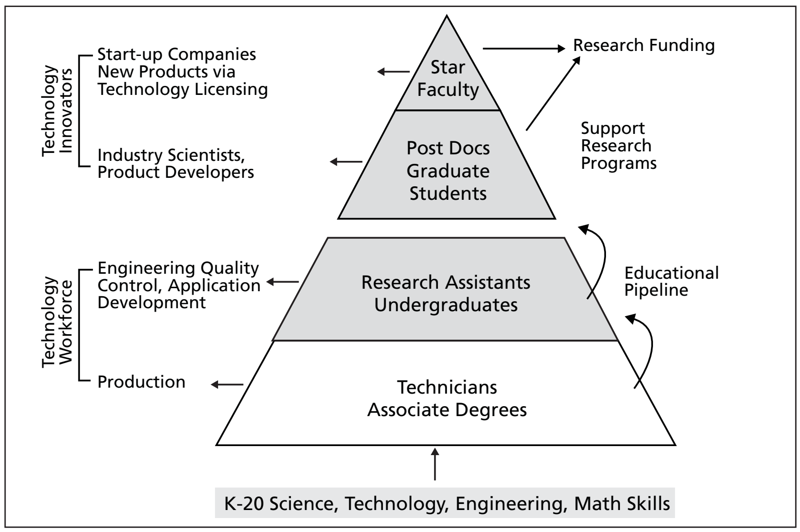
"CEOs report that the availability of technically trained talent is their top priority—one that often determines where they locate high-value investments."

What is often not recognized is that generating talent pools is a key contribution of university research and development activities to regional competitiveness.

Much is written about the importance of university technology-transfer and commercialization to move research discoveries into the marketplace and fuel product innovation, new firm formation and the broad economic success of a region. But perhaps the most important technology transfer of university research is the specialized technical workforce and future entrepreneurs who in turn strengthen existing industries and advance emerging technology sectors.

Talent generation is key not only for research, but for driving economic growth from product development through manufacturing and production.

Figure 2: Generate jobs, investments, wealth, pay taxes



These talent pools do not begin with educating students, but with the research faculty advancing university research excellence. States must be able to recruit and retain the best and brightest faculty if they are to be world-class leaders in science and technology development. In turn, top faculties are able to recruit top students at both the undergraduate and graduate level.

Just as important as having top flight faculty and research programs is having excellence across the educational pipeline. A vision of success in advancing a technology-based economy—one with leading firms what innovate and bring those innovations to market—is one that demands a broad range of skills.

Even manufacturing depends on ensuring quality talent.

Manufacturing remains a key driver for the Massachusetts economy. Five of the nine key statewide technology innovation clusters identified by the Mass Tech Collaborative are found in manufacturing, including:

- Computer and communications hardware;
- Defense manufacturing and instrumentation;
- Diversified industrial support ranging from materials industries (paper products, plastics, metals, coatings, rubber) to machinery industries (industrial, electrical equipment);

- Healthcare technology including medical devices, biotechnology and pharmaceuticals; and
- Textiles and apparel.

A study by the Massachusetts Taxpayers Foundation, “Dynamics of Growth: The Two Massachusetts Economies,” points out that manufacturing constitutes 74 percent of the economic base of “Outer Massachusetts” lying beyond I-495.

Massachusetts’ ability to compete in manufacturing as identified in *Manufacturing Matters* depends on its ability to “produce items customized for individual clients with fast turnaround, quick delivery and essentially no inventories—a model that’s possible through new production processes requiring high-skill labor.”

Indeed, the bottom-line measure of the success of the efforts to advance strategic alliances and Massachusetts’ position in technology innovation is jobs and more competitive businesses. As Greg Shelton, senior vice president of Raytheon and a member of the Steering Committee, declared, **“the goal of identifying opportunities for research investment is not just to increase the level of research funding for its own sake, but to capture the economic benefits for Massachusetts from these research investments.”**

This requires Massachusetts to identify those areas of manufacturing where it can be competitive—such as initial generation of innovative products, or ongoing customized, precision-oriented manufacturing—and to ensure the availability of the talent needed to be a leader in that cutting-edge manufacturing work.

Investment in stars, with an industry link

A UMass Success Story: Private Investment, an Academic Star and State Match Funds

An example of the types of strategic, targeted state investments needed by UMass, which can then be leveraged to grow research excellence and funding, is found in the area of remote sensing.

During the late 1990s, the state supported an endowed chair matching program whereby they gave the University 75 cents on every private dollar raised to endow a faculty chair. Amherst raised $850,000 of private funding for an endowed chair and the state provided a $650,000 match for a total of $1.5 million.

The campus then recruited Dr. David McLaughlin to hold that chair. Dr. McLaughlin eventually provided the leadership that led to a highly competitive NSF proposal with key industry partners, such as Raytheon, for a $40 million Engineering Research Center in remote sensing. During the competition, the state invested $5 million of capital funds as a state match, and Massachusetts is now the proud home of a national R&D center in Western Massachusetts, one that Raytheon believes will assist in the development of next generation sensor technology and serve as a major new generator of talent for the industry.

A Georgia New Economy Success Story

In 1990, a consortium of Georgia business leaders conceived and founded the Georgia Research Alliance (GRA). GRA was designed to bring together business, government, and higher education to develop research capabilities and assist technology-based industry.

Since 1991, Georgia has invested $312 million into GRA-directed programs to construct state-of-the art research facilities and laboratories and attract eminent scholars to Georgia universities. GRA measures its success in terms of increased university research and development expenditures, establishment and growth of new technology companies, and growth in high technology jobs.

- During the last ten years R&D expenditures in Georgia have doubled, increasing from $400 million annually to $800 million.
- In 1995, about $100 million a year was being invested in start-up companies in Georgia, in 2001, more than $873 million was invested.
- Between 1995 and 2001, Georgia added 59,600 high technology jobs, moving the state to rank eighth nationwide in high technology employment.

Massachusetts' R&D Strengths: Ten Core Technologies

Massachusetts cannot advance its position in technology development—and promote needed strategic alliances in emerging technologies and innovation—without understanding its key focus areas and how it is positioned across the many research and technology areas. Much is said about information technology, biotechnology and nanotechnology, but the Massachusetts research base is far more extensive in both industry and universities than just these "hot" areas of popular technology interest.

A technology road map is a tool for educating decision-makers and building consensus for action.

Not all states are built alike in technology, and it is the differences in a state's technology portfolio that can best define how a state can succeed in technology-based economic development. Moreover, states are learning that to gain economic value from their research universities they need to assess the specific areas of research focus and excellence found at these knowledge engines and determine how they are linked to industry efforts and to broader market opportunities, particularly those that offer platforms to industries of the future.

The purpose of this technology road map of core technology focus areas, then, is to help set a focus and drive results in science and technology initiatives. It helps answer the following questions:

- What are the specific areas of core technology focus found across industry and universities in Massachusetts?
- How does the state stand competitively in research activity, industry development and talent generation in these core research focus areas?
- What are the guidelines for pursuing specific opportunities that build on our core technology focus areas?

This is the first-ever all-encompassing study of the technology focus areas for Massachusetts and how the state is positioned. But this emphasis on research and development is not an end in itself; rather it is a key means for advancing the Massachusetts economy.

A breadth of core technology strengths is found in Massachusetts.

A detailed analysis of patent and grant activities, areas of publications strength and follow-on interviews with industry executives, teaching hospital official,s and university officials and faculty members has led to the identification of **ten core focus technology areas**: seven primary areas of core technology focus and three additional cross-cutting application areas.

This is a substantial range of activities for one state, especially one with just over six million people. This breadth of research activity points to Massachusetts' legacy as a world-class R&D provider.

Key Points on Massachusetts Core Technology Focus Areas

- Substantial breadth in core technology focus areas—Massachusetts enjoys a balanced portfolio with ten core focus areas identified.
- Massachusetts is a leader across core technology focus areas in numbers of technology firms, numbers of graduates and research excellence.
- Massachusetts shows signs of weakness compared to other leading states in size of technology firms, growth rates in new graduates and low standing in associate degrees needed by technicians.

Primary technology focus areas (non-life sciences).

1. **Advanced materials** is a core technology focus for many of the leading firms found in Massachusetts, including Cabot, Gillette, Spalding Sports and General Electric. Many Massachusetts universities excel in advanced materials research, including MIT, Harvard, UMass Amherst, Northeastern, Tufts, Worcester Polytechnic Institute and UMass Lowell. This provides the state a significant and wide-ranging research focus extending from traditional material competencies in the development and fabrication of polymers, metals, alloys and ceramics, as well as advanced materials development involving novel properties and nanoscale materials.
2. **Signal processing in electronics and optical systems** involves companies across many industry segments, including Analog Devices, Raytheon, Teradyne, EMC and Verizon. As a technology focus, signal processing is key for telecommunications, electronic systems and radar/guidance control involving the interface and systems integration of software and hardware to deliver new capabilities within embedded systems. A number of research universities in Massachusetts excel in signal processing including MIT, Boston University, UMass Amherst, Harvard and Worcester Polytechnic Institute (WPI).
3. **Computer sciences** is firmly rooted in the economic landscape of Massachusetts' technology industry base, particularly with its substantial software industry. There are literally thousands of firms developing key software applications and new computer-related technologies. Leading university research programs are found at MIT, UMass Amherst, Harvard and Boston University. And many of the state's universities and colleges excel in generating the talent in computer science that companies in Massachusetts require. Massachusetts is particularly strong in computer networking, data storage and management and vertical applications.
4. **Sensing, optical and electro-mechanical devices** is an unheralded backbone of the Massachusetts technology fabric. Wide ranging companies are leaders in technology innovation in this focus area, from Boston Scientific to Thermo Electron to Raytheon to Analog Devices. Not only are leading research programs found at MIT, UMass Amherst and Harvard, but also at Northeastern and Tufts. Expertise in developing devices is also found at other universities in Massachusetts with strong engineering traditions such as WPI and UMass Lowell. This focus area involves broad applications of machinery, measuring, sensing, lasers and actuators, and is a major element found in patent clusters in Massachusetts, reflecting the state's traditional capabilities in precision machining.
5. **Environmental sciences** is a strength found among university and research institutions, and involves marine science and oceanography, ecosystems, climate research, and earth sciences. Top-rated research programs are found at MIT, Harvard, UMass Amherst and Boston University. Woods Hole stands out as a unique research center in environmental sciences, UMass Dartmouth is developing a unique system-wide School for Marine Sciences, and UMass Boston has a strong focus in environmental sciences as a university-wide core competency. Industry development is found not only in leading environmental engineering firms, such as CDM and Clean Harbor, but in a highly specialized industry concentration of oceanographic companies in Southeastern Massachusetts and in makers of instruments and monitoring devices. Interviews identified many emerging areas from green chemistry to environmental genomics to integrated sensing and environmental information management systems.

Massachusetts' Ten Core Technology Focus Areas

1. **Advanced materials**
2. **Signal processing in electronics and optical systems**
3. **Computer sciences**
4. **Sensing, optical and electro-mechanical devices**
5. **Environmental sciences**
6. **Genomics and proteomics**
7. **Disease-related research and drug discovery**
8. **Biomedical device technologies**
9. **Renewable energy**
10. **Nanotechnology fabrication**

Primary technology focus areas (life sciences).

Life sciences is a considerable strength in Massachusetts, with a significant base of activity in university and teaching hospitals and a growing industry presence. The analysis of patents points to two core focus areas, which cut across disease areas.

6. **Genomics and proteomics** is a basic staple of Massachusetts' leading biotechnology sector with Millennium Pharmaceuticals and Genzyme, the key leaders. Massachusetts has a superior concentration of teaching hospitals and medical schools delving into fundamental research on genomics and proteomics as well as clinical research aspects, led by Partners HealthCare System, Harvard, UMass Worcester, Tufts and Boston University (BU). Massachusetts also brings advanced computational strengths and basic biological approaches to studying genomics and proteomics, with MIT and Harvard having notable programs and unique collaborations, particularly the Whitehead Institute and the newly formed Broad Institute, and Boston University emerging with key capabilities. This area of technology focus is fast-paced and constantly evolving. It involves protein analysis, detection of genetic mutations, gene expression, gene therapy, and transgenic models, among other activities.
7. **Disease-related research and drug discovery** patent clusters present a cross-cutting disease focus from cancer to neurological diseases to infectious diseases. Key companies generating patents include Millennium Pharmaceuticals, Vertex Pharmaceuticals, and Sepracor. Partners HealthCare System is also a major patent generator. Research extends from the state's leading medical schools and teaching hospitals, through specific program efforts found at MIT, UMass Amherst and UMass Lowell. There is a major focus on development of new drug agents, particularly inhibitors, as well as more effective drug delivery.

   The analysis of NIH grant activity revealed four disease-specific areas in disease-related research and drug discovery, though these are not fully investigated in this part of the report:

- *Immunology and infectious diseases* – There are major efforts in HIV treatment, therapeutics and drug resistance, monoclonal antibodies for vaccine development, viral and bacterial pathogenesis, and asthma and other respiratory diseases. Massachusetts universities and teaching hospitals were major recipients of the latest round of bioterrorism funding, including a major national biocontainment facility at BU, Tufts-UMass Dartmouth National Botulinum Center, and new NIH-funded research centers on human immunity and biodefense at Dana Farber and UMass Medical School.
- *Cancer* – There is a key focus in Massachusetts on tumor cell biology, drug discovery and development and risk and prevention studies.
- *Cardiovascular* – There are major activities in cardiomyopathy, diabetic-related cardiovascular disease, hypertension, heart devices, and epidemiological studies of cardiovascular disease and prevention.
- *Neurosciences* – This is a major area of NIH activity with ongoing efforts in brain imaging, Alzheimer's disease, Parkinson's disease, Huntington's disease, molecular aspects of depressive disorders, visual pathways and processes, neural cell death, and neurobiology of behavior and drug addiction. Major investments are underway across many Massachusetts institutions to advance neurosciences in the years to come.

The NIH grant activity also points to major cross-cutting activities in basic biological sciences, as well as a strong base of clinical research and health studies in Massachusetts. The basic biological sciences efforts involve molecular and genetic analysis to cell biology, including stem cell research, comprising over 11 clusters and 1,300 active NIH grants. The strong base of clinical research is evidence of Massachusetts' ability to link its basic research activities with its outstanding clinical care strengths and translate new research discoveries into clinical practice. Funding is aggregated into two main clusters of NIH grant activity with over 1,100 active NIH grant awards.

Cross-cutting technology focus areas.

While not identified separately from the cluster analysis of patent and grant activities, the follow-on interviews identified three cross-cutting application areas, which draw upon primary technology areas and are rising quickly as their own areas of focus.

8. **Biomedical device technologies** bring together the advancing knowledge of biological processes and mechanisms with the systematic approaches and innovations found across engineering from nanotechnology to information technology to material sciences.

- *Biomedical applications are a key component of a number of industry related core competencies*. Progress in biomedical devices is increasingly dependent on leadership in a wide range of disciplines, and Massachusetts has strength across those disciplines. Massachusetts' leadership in the core focus areas of sensors, optical and electro-mechanical devices, genomics, proteomics and signal processing combine to make Massachusetts an attractive location for new and existing companies pursuing the development of improved devices and instrumentation to improve human health and quality of life.
- *Presence of leading bioengineering programs across research drivers.* There is a substantial and growing base of biomedical device technologies at research institutions in Massachusetts. The more formal activities are found at: Partner HealthCare System, MIT, Boston University and Worcester Polytechnic Institute. The interviews revealed just how pervasive biomedical devices technologies are beyond formal bioengineering programs. For instance, Lincoln Labs first began looking at bioengineering issues around the time of the first Gulf War. They have built labs and hired biologists to complement their existing engineering strengths and now have an active effort focused on the rapid detection of pathogens and other biological detectors. Or consider how UMass Lowell's earlier work in material science instrumentation has now led to a research program in breast cancer diagnostics. At Northeastern's Center for Subsurface Sensing and Imaging Systems, an NSF-funded Engineering Research Center, in which Boston University is a partner, advanced work in 4D imaging is leading to significant biomedical advances for smart radiotherapy with Mass General Hospital, as well as multi-modal breast imaging. A promising newcomer is the Center for the Integration of Medicine and Innovative Technology, a strategic alliance of Partners HealthCare System with MIT, the Charles Stark Draper Laboratory and Beth Israel Deaconess Medical Center, that identifies and advances technological solutions to perplexing healthcare problems.

9. **Renewable energy** builds upon many research strengths found in Massachusetts, including polymer strengths, green chemistry strengths, and microbial energy sources. A 2001 study by Case Western Reserve University ranked Massachusetts 3rd in the nation for university research in technologies driving fuel cell-related science and engineering.

- *Key programs are found across research drivers.* Worcester Polytechnic Institute is home to the Fuel Cell Center, a university-based research program with industry members undertaking research on technologies for stationary and portable fuel cells. UMass Amherst, for instance, has received significant national recognition for its work in developing biobatteries harnessing the conversion of waste organic matter to electricity and enabling key applications such as remote sensing, conversion of renewable biomass to electricity, and conversion of methane to electricity. MIT has a number of alternative power research efforts including an interdisciplinary program through its Center for Materials Science and Engineering in solid-state portable power sources and its Laboratory for Energy and the Environment involving multi-disciplinary research including advanced nuclear power research and deployment of solar power. UMass Boston is engaged in development of fuel cell technology and solar energy conversion through its Green Chemistry program. Tufts has a number of projects dedicated to the development of synthetic processes that utilize less toxic solvents and materials. In polymer chemistry, Tufts investigators have developed a unique method for creating polymeric microstructures with a variety of sizes, shapes, and chemical compositions.
- *Growing base of industry activity.* A growing list of innovative companies is advancing renewable energy alternatives, including fuel cells, photovoltaic, and wind power. There are 18 fuel cell related companies in Massachusetts. These companies are developing both portable and stationary fuel cell power generation systems, components, and fuel processors. In photovoltaics, Massachusetts is second only to California in terms of number of manufacturing firms located in the state. There are about twelve companies in Massachusetts—most of which are small operations that offer retail, installation and maintenance services. Massachusetts is also home to significant manufacturing capacity for solar cells and modules, and there smaller companies that specialize in sub-segments such as solar-battery combinations. Massachusetts has ten companies involved in wind power generation.
- *Key enablers with the Massachusetts Renewable Energy Trust Fund (RET) and the Strategic Envirotechnology Partnership (STEP).* Massachusetts has committed funds to the significant deployment of renewable energies through the Renewable Energy Trust Fund. This fund provides financial support for photovoltaic applications, fuel cell feasibility assessment, and green power incentives with renewable energy system owners. Administered by the Massachusetts Technology Collaborative, relevant major initiatives of the RET include: the premium power program, the green buildings program, the green power pre-development program, the solar-to-market program, and assistance to firms to encourage their continued presence and expansion in Massachusetts. Another effort is the Strategic Envirotechnology Partnership (STEP), established in 1994, a joint program between the Massachusetts Executive Office of Environmental Affairs and the University of Massachusetts to assist businesses with the development and promotion of innovative, technology-based solutions to environmental problems in

the Commonwealth. While reduced in scope in recent years due to state budget cuts, this program provides technical assistance, business assistance, regulatory and permitting assistance, and access to markets (Massachusetts and other states).

10. **Nanotechnology fabrication** is an emerging area of focus in Massachusetts cutting across many universities. Not only is Massachusetts one of the top states in nanotechnology research funding, it boasts the top three institutions receiving NSF funding in nanotechnology over the FY 2001 to FY 2003 period—Harvard, UMass Amherst, and MIT.

- *Harvard* is home to one of the leading national centers, the Nanoscale Science and Engineering Center in partnership with MIT and several out-of-state institutions. This broad-based research effort focuses on the fundamental properties of nanoscale structures including the construction and testing of new types of electronic and magnetic devices primarily from nanocrystals or nanomagnets. Critical to advancing Harvard's position in nanotechnology was the university's investment in the Center for Imaging and Mesoscale Structures, involving high end microscopes, an electron-beam lithography system, and clean rooms for nanofabrication.
- *UMass Amherst*, a leading recipient of NSF-funded nanotechnology grants, is advancing the use of polymer templates for nanofabrication to create the pattern of a device's structure to be used for microelectronics, sensors, optical, and magnetic devices. Other key research includes functional nanoparticles, hybrid materials, porous materials, self-assembly of nanoscopic structures, nanoparticle synthesis, magnetic and electronic properties of nanostructures, and biological molecular systems. UMass Amherst recently announced the formation of MassNanoTech as an active partner with industry to spawn technologies that are integrated with emerging technology platforms.
- *MIT*, beyond its involvement with the Harvard-led Nanoscale Science and Engineering Center, has a broad range of activities including: the Institute for Soldier Nanotechnologies, a multi-interdisciplinary effort focusing on applying nanotechnology to the development of next generation battlesuits with capabilities in detection, energy absorption, and mechanically active materials for devices and exomuscles; the Nanostructures Laboratory, developing techniques for fabricating surface structures with feature sizes in the range from nanometers to micrometers; and a NanoMechanical Technology Lab in the Department of Materials Sciences, probing changes in mechanical behavior at the nanoscale for living cells, designer polymers, bioceramics, optoelectronic materials, surface coatings, and metals.
- *Northeastern* leads an NSF-supported Industry-University Cooperative Research Center focused on contamination and fabrication.
- *UMass Lowell* has an Institute for Nanoscience and Engineering Technology and has been a leader in advancing new nano-based technologies for processing polymer sheets with photovoltaic properties.
- *BU* is advancing bio-nanotechnology, including a new technology to image biomolecules, and nano-based chip development for holding high-density protein arrays for basic research, drug discovery, and medical diagnosis.

A look at Massachusetts' competitive position in the core technology focus areas is mixed.

It is necessary to consider three major areas in analyzing the competitive position of Massachusetts—industry base of activity, talent generation and research excellence.

The **industry base of activity** in the core technology focus areas: for many, this is the key outcome measure of a state's position in a technology focus area, because it reveals whether the state has been successful in translating these technology focus areas into economic gains and jobs.

The **talent level** being generated in the core technology focus areas: talent is becoming a leading factor in attracting industry investments and location of firms. It is a critical output of the state's activities in a core focus technology area.

The **research competitiveness** of universities in the core technology focus areas: a key indicator of future strength in a technology area is the presence of research drivers to fuel innovation and generate specialized pools of talent.

On a positive note:

- *Massachusetts has leading research institutions in all of the core technology focus areas.* The key strengths of MIT, particularly in the engineering and physical sciences, and Harvard, particularly in the life sciences, are renowned. In selected areas, other Massachusetts institutions are among the top in the nation, such as Boston University in IT and communications systems and in AI, robotics and auto control; UMass in polymer sciences, computer sciences, IT and communication systems; UMass Medical in genomics; and Tufts in biotechnology and pharmacology.
- *Massachusetts is a national leader in the number of firms across nearly all of the core technology focus areas.* Massachusetts is ranked second or third among all states in number of firms in eight of the core technology focus areas, and sixth in advanced materials *(see Table 7)*.
- *Interestingly, many of these core technology focus areas have a strong presence outside of Route 128.* In three core technology focus areas, less than half the firms are found in the Greater Boston region—only 39 percent of the advanced materials firms, 45 percent of the sensing, optical and electro-mechanical devices, and 46 percent of the signal processing, and environmental systems. The life sciences and computer sciences, including the software industry, are highly concentrated in the Greater Boston region.
- Massachusetts ranks among the top states in total numbers of graduates, and is particularly strong in advanced degrees at the masters and PhD level.

Several challenges stand out:

- *Massachusetts technology firms are generally not leaders in size of firms.* Across nearly all core technology focus areas, in its size of technology firms, Massachusetts is not among the top five states—a key contrast to its position relative to the number of technology firms. The one core technology focus area where Massachusetts is in the top five in size of its firms is biomedical devices. This suggests that Massachusetts is not a national leader in the growth of young, small, and medium-sized technology firms, having lost many of its large technology anchors within the past two decades.

Table 7: Summary of Massachusetts' position in core focus areas across industry, talent, research measures: state ranking

Summary of Massachusetts Position in Core Focus Areas Across Industry, Talent and Research Measures: State Rankings

	INDUSTRY PRESENCE		TALENT GENERATION		RESEARCH EXCELLENCE	
	Number of firms	Employment controlled by Massachusetts firms	Total degrees awarded, 2001	Change in degrees awarded, 1996 to 2001	Total state funding in related-university research fields	Leading institutions in total citations (top 25 in nation) and reputational rankings for related fields
Advanced Materials	◗ 6th	⊖ 12th	◗ 7th	⊖ 36th	◗ 10th in metallurgical and materials engineering	MIT UMass Amherst Harvard
Signal Processing	● 2nd	◗ 8th	◗ 9th	⊖ 17th	◗ 6th in electrical engineering	MIT Harvard
Computer Sciences	● 2nd	◗ 9th	◗ 8th	⊖ 16th	◗ 6th in computer sciences	MIT Harvard UMass Amherst Boston University
Sensing, Optical and Electro-mechanical Devices	● 3rd	⊖ 11th	◗ 8th	⊖ 22nd	● 5th in mechanical engineering	MIT
Environmental Sciences	● 3rd	◗ 10th	◗ 8th	⊖ 38th	● 3rd in earth sciences	MIT Harvard
Genomics and Proteomics	● 2nd	◗ 9th	◗ 7th	⊖ 43rd	N/A	Harvard MIT Tufts UMass Worcester
Disease Research and Drug Discovery	● 3rd	◗ 9th	◗ 6th	⊖ 39th	N/A	Harvard/Partners Boston University Tufts UMass Worcester
Biomedical Devices and Instrumentation	● 2nd	● 4th	◗ 8th	⊖ 38th	N/A	MIT Harvard
Renewable Energy	● 3rd	⊖ 16th	◗ 8th	⊖ 25th	N/A	MIT
Nanotechnology Fabrication*	N/A	N/A	N/A	N/A	N/A	MIT Harvard UMass Amherst

Key: Ranking 1–5 = ● **Leader** Ranking 6–10 = ◗ **Challenger** Ranking 11–up = ⊖ **Follower**

- Industry presence based on CorpTech data.
- Talent generation based on National Center for Educational Statistics data.
- Research excellence based on NSF data on university research funding, publications data from Institute for Scientific Information and reputational survey rankings from US News & World Report.
- *Nanotechnology rankings based on recent NSF funding awards under the National Nanotechnology Initiative for top institutions, FY2001–03.

- *Massachusetts lags behind in technical education degrees awarded at the associate degree level.* Massachusetts is not among the nation's leaders in associate degrees in technical fields related to the core technology focus areas. Massachusetts' ranking in associate degrees range from 8th in genomics and proteomics to 20th in biomedical devices. This suggests that Massachusetts may have difficulty retaining production-related activities—an important part of the Commonwealth's technology base and one that can even become more value added based on the core research strengths of the state's higher education institutions.
- *Massachusetts is declining faster than the nation in most degree areas associated with core technology focus areas.* Massachusetts is well off the pace of other states in degrees generated from 1996 to 2002. Across the nation—with the exception of computer sciences—these technology-based fields have been in decline and Massachusetts has generally exceeded the national decline, resulting in poor ranking overall. There is some positive news. Massachusetts exceeded the strong growth found nationally in computer science graduates, and the state has recorded slight growth in signal processing-related degrees of one percent while the nation overall fell by five percent.

Another warning sign is that Massachusetts is falling behind in the growth of many key university research fields associated with its core technology focus areas.

For the nation, all major fields of university research continue to enjoy a rising level of research funding. But in Massachusetts the pattern is more uneven. There are clear winners and losers in university research in Massachusetts *(see Figure 3)*.

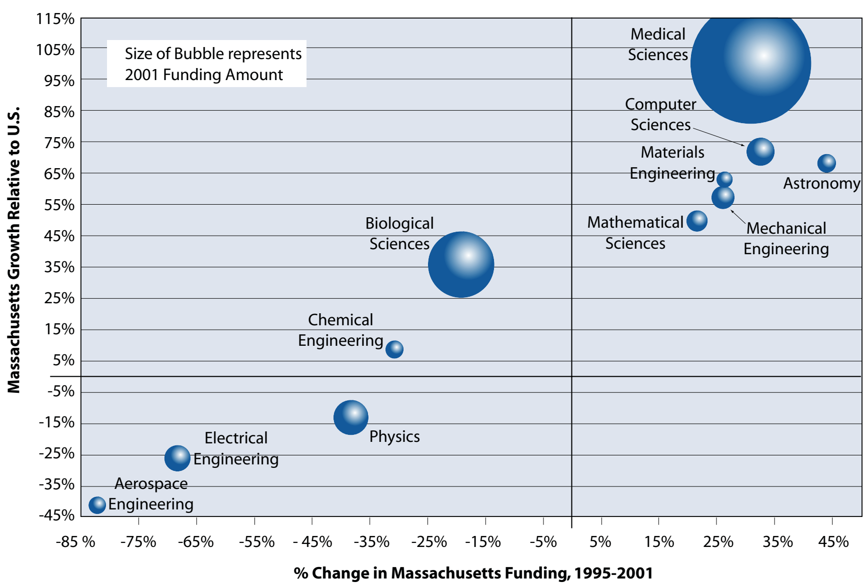
Among the winners are medical research, computational sciences and material sciences, all of which are outpacing the national growth rates in university research funding. This is good news for many of the core technology focus areas from advanced materials to computer sciences and the life sciences core technology focus areas.

Among the losers are electrical engineering and physics, which are declining in absolute funding levels in Massachusetts even as they are growing across the nation. This is of concern for signal processing, sensing, optical and electro-mechanical devices, and even advanced materials down the road if physics continues to decline. Other fields where Massachusetts is off the national growth pace include biology and chemical engineering, which suggests that the life sciences may not be as well off, with chemical engineering being a key discipline in emerging bio-scale-up technologies and biology underpinning future biomedical research understandings.

It is difficult to fully anticipate how this uneven pattern of university research

Massachusetts is experiencing shifting priorities in research across its universities, resulting in uneven research funding growth by field compared to national trends.

Figure 3: University Research Funding by Field, 1995 to 2001



Source: National Science Foundation, calculations by Battelle emphasis will affect the economic prospects of Massachusetts' technology sectors. The concern is whether industry can access the sources of technology expertise and talent it depends on from local universities, as the university base in Massachusetts grows more and more oriented towards the life sciences and computational sciences.

Uneven university-industry connections across the ten core technology focus areas

Massachusetts is well known for how much of its technology base has emerged from its university research centers. This points to the important role that universities play in generating talent—the scientific originators, scientific workforce and entrepreneurial managers needed to form and lead new companies.

Moreover, key university centers, such as UMass Lowell's Plastics Processing Center, Boston University's Photonics Center, WPI's Bioengineering Institute and the Partners HealthCare/MIT/Draper Labs Center for Integration of Medicine and Innovative Technology (CIMIT) alliance, are actively supporting existing and emerging firms in Massachusetts. The Regional Technology Alliance in western Massachusetts and Telecom City in the Greater Boston area have made strides in university-industry collaboration. The Telecom City consortium has submitted joint research applications for federal funding in wireless grid technology, emergency services, and bioinformatics. And, today, the Greater Boston region is attracting research centers of major pharmaceutical companies, such as Novartis, Abbot and Merck, so they can be close to the cutting-edge of leading biomedical research.

Massachusetts is falling behind key state competitors in industry support for university research.

Table 8: Industry support for university research in 1994 and 2001

1994	2001
Pennsylvania – $112.0 million	California – $253.0 million
California – $105.8 million	Texas – $175.8 million
Texas – $96.5 million	North Carolina – $167.6 million
Massachusetts – $95.7 million	Pennsylvania – $161.1 million
North Carolina – $67.5 million	**Massachusetts – $153.4 million**

Source: National Science Foundation

However, the evidence continues to mount that the connection between industry and universities is not what it could be. Massachusetts is not keeping pace with leading competitor states in the growth in industry support for university research and development. In 1994, Massachusetts stood at $95.7 million in industry funded research at universities—a mere 16.3 million lower than the national leader, Pennsylvania. By 2001, Massachusetts had increased to $153.4 million, a healthy rise of 60.3 percent that exceeded the national average of 57.8 percent. But many key competitor states surged even more strongly. North Carolina rose from $67.5 million in 1994, well behind Massachusetts, to overtake Massachusetts by 2001 with industry support for university research reaching $167.6 million. Texas has outpaced Massachusetts growth and from being nearly equal, is over $20 million higher than Massachusetts. And, California has surged ahead, going from roughly $10 million higher in industry support for university research than Massachusetts to approximately $100 million higher by 2001 *(see Table 8)*.

For the purposes of this project, input was gathered from 74 technology companies in Massachusetts, of which nearly 85 percent have an active research and development program. A review of the input received by companies on the state of industry-university collaborations reinforces the sense that Massachusetts industry and universities are not as well engaged as they might be. These results are not posed as a scientifically valid survey, rather an indication that industry is not taking advantage of the opportunities offered by Massachusetts universities.

- Only slightly more than half of the companies interviewed that are engaged in research activities have active research-related collaborations with universities, involving sponsored research, technology licensing, technical problem solving or use of facilities.

- Surprisingly, of those who do have university relationships, they typically involve both Massachusetts and non-Massachusetts universities. A smaller sample of these firms—51 out of the 74—indicate that they are as likely to go out-of-state as in-state for the broad range of industry-university research-related collaborations, including sponsored research, technology licensing, technical problem-solving, use of facilities and equipment, and workforce training.
- Across the technology fields there is a wide variation in the extent of industry-university relationships. For technology firms engaged in computer sciences—drawn from IT, communications, finance and defense sectors—a mere seven out of 35 firms contacted have university research relationships. On the other hand, all of the technology firms engaged in drug discovery and genomics and proteomics have university research-related collaborations as do nearly all of the technology firms engaged in nanotechnology (contact was with six to seven companies engaged in each of these technology fields). Advanced materials, signal processing, sensing, optical and electro-mechanical systems and biomedical engineering—with contact ranging from 15 to 23 firms for each technology focus area—follow the overall pattern of 50-50 involvement in university-related research.

At the same time, interviews with university research leaders continually illustrated that many of the industry members of major university research centers in Massachusetts are from outside of the state and few are local. While this reflects the scientific importance of Massachusetts research institutions for the world community, it suggests a missed opportunity for the state.

- The long-standing Center for University of Massachusetts-Industry Research on Polymers; major industry members include 3M, Bayer, BP, Eastman Kodak and ExxonMobil.
- The Metal Processing Institute at Worcester Polytechnic Institute is a leading research center for near-shape metal products, an industry estimated to be $70 billion. More than 110 of its 120 members are found outside of Massachusetts, reflecting the diversity of its industry base.
- The newly formed MIT Microphotonics Center has a number of leading Massachusetts firms, such as Analog Devices, but also many from outside of the state and nation, such as Pirelli Labs and Walsin Lihwa Corporation.
- Technology licensing activity at UMass, which has grown tremendously in the last several years and now stands at 17th in the nation in licensing income, is primarily with out-of-state firms, as is the case with the state's private universities.

The sense that emerges from discussions with industry and university officials is the untapped potential that exists in Massachusetts for broader, more exciting collaborations and strategic alliances. Many of the industry and research institutions remain isolated, with only episodic collaborations, most typically one-on-one.

The major concern for Massachusetts is not that there will no longer continue to be strong research drivers or a substantial technology base, but that the impact and influence it wields will be eclipsed by other states and nations. In short, Massachusetts will lose its competitive edge and risk having technologies developed and commercialized in other states and nations.

Observations on Collaborations by Core Technology Focus Areas

Across the core technology focus areas, input from discussions with universities, teaching hospitals and industry, suggests that there is much room for improvement in collaborations with industry and between universities:

Advanced materials has one of the closest industry-university collaborations found in Massachusetts with such efforts as the plastic processing program at UMass Lowell and powder metals institute at WPI. Discussions with several of the major materials firms suggests that they are involved with universities outside of Massachusetts. In addition, there is a lack of collaboration across universities to pool their competencies and advance broader partnerships.

Signal processing is an area where industry activities outstrip the efforts found in universities today. Federally supported labs in Massachusetts, especially those associated with the Department of Defense, such as Lincoln Labs and MITRE, have a strong competency in signal processing. From discussions with industry, a critical role universities play in advancing the state's core strengths in signal processing involves generating talent for industry.

Computer sciences is another area where talent generation of universities is crucial to industry. Massachusetts universities have responded strongly to the rising demand for computer workers, and continue to deepen their linkages with industry through new NSF funded educational activities, despite the lack of funding support from the state for the Commonwealth Information Technology Initiative. This is an area where universities, led by UMass, are actively working with community colleges and secondary schools to ensure a well-trained workforce.

Sensing, optical and electro-mechanical devices is an area where there is an active base of both industry activity and university research activities, though the decline in university research in electrical engineering is a worrisome trend. One important area of application is in medical devices where there appear to be active collaborations. Sensing is also an area of significant research across universities, but the levels of collaboration across universities could be greatly enhanced.

Environmental sciences is an area where university research is well ahead of industry activities and is an important source of talent generation. Given the small size and emerging nature of many environmental firms, this is an area where having the capacity for the university to have shared laboratory and prototyping facilities is of great importance.

Life sciences is an area that exhibits strong linkages between university and industry, particularly in biotechnology. Massachusetts is also succeeding in attracting research facilities of large pharmaceutical companies seeking to expand their research activities into more genomic and other biological research areas given the strong base of research activity found at teaching hospitals and medical schools in Massachusetts. Life sciences is also bringing new public-private partners together, such as the Baystate Medical-UMass Amherst new biomedical research institute and the collaboration of Tufts and UMass Dartmouth in botulism research. Still, life sciences is also an area in Massachusetts where the gaps in going from research discoveries to commercialization are among the most difficult to bridge, and where capturing the downstream benefits of manufacturing are uncertain. It is also an area where multi-institutional partnerships across universities and teaching hospitals is just beginning to emerge, though collaborations at the Principal Investigator level appear to be common.

Biomedical devices is an area where Massachusetts has one of the most successful strategic alliances in the nation with the continued development of CIMIT—a strategic alliance of Partners HealthCare System, MIT, Draper Labs and a growing roster of medical device companies. Generally, from our interviews we have found academic health centers are open to collaborating with industry. Bioengineering experts are eager to be involved in strategic alliances bringing together industry and clinical partners.

Renewable energy is a niche area where Massachusetts has in place a mechanism to advance new technology development through the Mass Tech Collaborative renewable energy fund. Nevertheless, the ongoing research activities in Massachusetts are too early stage for MTC. Similar to the environmental sciences area, the base of companies are typically small and emerging and so not able to easily partner with universities.

Nanotechnology is an emerging area where it is still not clear whether industry and universities will closely connect. Today, Massachusetts lacks a federally-funded user facility, such as at Cornell, which constrains collaboration. Moreover, there is a mixed record of licensing technologies being generated by nanotechnology research, with one highly successful new start-up taking root in Massachusetts, Konarka, but other key technologies being licensed to California-based companies.

Choosing to Lead: The Massachusetts New Economy Agenda

Entering the 21st century, Massachusetts brings an ad hoc approach to advancing its science and technology competitiveness that consistently falls short in the face of the mounting competition and changing needs. Of particular concern is that Massachusetts is not seizing the potential of its research base to promote broad-based economic growth and strong positions in emerging technology areas. Unlike other states that have integrated technology initiatives that promote research leadership as well as the development of that research into new products and companies, Massachusetts leaves much to chance.

In many ways, the wealth of Massachusetts' technology base resides in silos, where individual universities, technology businesses and other research drivers make isolated decisions on how to advance their research position, and fail to draw strength from the larger concentration of efforts found in the state.

What we risk and what we can gain.

Ultimately, the imperative for Massachusetts in establishing a world class science and technology initiative is to better position itself across a broad range of emerging technologies to create jobs and economic growth.

For example:

- Today, Massachusetts is home to a number of leading nanotechnology research programs. *Can Massachusetts translate this into a leadership role by forming an industry research network in nanotechnology manufacturing?*
- BusinessWeek calls one of the next mega trends in technology development the oncoming "sensor revolution." Massachusetts has a range of activities in industry and universities focused on sensing and imaging technologies, but they tend to operate in isolation from each other. *Can Massachusetts establish the needed partnerships and facilities to further the commercial development of sensing and imaging technologies across medical, security, supply-chain, traffic control and many other applications?*
- The untapped potential of the ocean for unique materials and drug agents is another future area of technology discovery. *Can Massachusetts, one of a handful of states with active research programs, brings its institutions together to be a leader in mining the technological potential of the oceans?*
- Life sciences is among the most promising growth sectors. *Can Massachusetts' universities and teaching hospitals overcome the formidable challenges in commercializing their research discoveries, and capture the downstream benefits of biomanufacturing?*
- Next generation IT/communications platforms, which can integrate remote sensing and detection data, conduct real-time analysis and simulation, and ensure robust, self-healing computer networking and communications capabilities, are critical for homeland security and defense-related command/control systems. Massachusetts offers a unique capability to develop and implement such an advanced platform across its federally funded laboratories and defense installations, universi-

Key Points on Massachusetts' New Economy Agenda

- Capacity building is critical—cannot assume that all areas of research and education needs will be met without targeted investment.
- New generation of technology collaborations need to be facilitated, matching funds not enough.
- Four key economic drivers for the future:
  1. Leverage Massachusetts' breadth and strengths by promoting multi-institutional strategic initiatives that reach not only across universities, but also among universities, industry and government.
  2. Improve the translation of research strengths into products and industry development.
  3. Strengthen the state's overall position in research and promote regional economic development by investing strategically in the University of Massachusetts.
  4. Develop a broader compact to ensure coordination across state and quasi-public agencies and communications across key stakeholders.

ties and defense-related companies. *Can Massachusetts build the partnerships to tackle such a complex endeavor?*

Most importantly, current economic forecasts call for Massachusetts to not keep pace with the national economic recovery, falling short of national growth in output and employment through 2007. Without a focused growth strategy built around our key economic assets of talent, research and innovation, these economic predictions will hold true.

Four economic drivers will sustain Massachusetts' technology competitiveness.

To move Massachusetts forward and ensure its technology competitiveness, the broad grouping of leaders from industry, higher education, teaching hospitals and economic development organizations identified four economic drivers upon which to build a sustained role for technology leadership:

1. **Leverage Massachusetts' breadth and strengths by promoting multi-institutional strategic initiatives that reach not only across universities, but also among universities, industry and government.**
2. **Improve the translation of research strengths into products and industry development.**
3. **Strengthen the state's overall position in research and promote regional economic development by investing strategically in the University of Massachusetts.**
4. **Develop a broader compact to ensure coordination across state and quasi-public agencies and communications across key stakeholders.**

These four economic drivers address Massachusetts' significant economic challenges:

- Maintaining its historic position of educational and R&D leadership, as a magnet for talent and driver for economic growth and job creation.
- Increasing the direct impact of the state's R&D base on its economy.
- Harnessing the state's R&D engine to drive economic growth in regions where we have room and need for growth.

The details for each of these four economic drivers are presented beginning on page 46. It is vital that Massachusetts take the critical steps to implement this plan of action.

Implementation requires a shared understanding of what it takes to succeed

Successfully implementation of the four economic drivers for sustaining Massachusetts' technology competitiveness requires industry, university and state government to assume new responsibilities and to work together in new ways. But it is critical that there be a shared understanding of what it takes to succeed.

First, the ability to establish specialized talent pools is the most critical factor for success. It is essential for growing a research base, ensuring the availability of entrepreneurs to start new companies, and generating technically skilled workers to attract and retain industry. But generating talent is not a separate activity from research—no university can lead the development of specialized talent without having strong research competencies and leading faculty to teach advanced, newly emerging fields and to attract quality students.

Second, **Massachusetts must recognize the need for a balanced portfolio of activities across technology areas** if it is to sustain its overall technology competitiveness. Massachusetts expertise across many technology areas. Getting too focused on just one area would undermine Massachusetts' overall technology competitiveness.

Third, public research universities have a special role to play in advancing technology development, given their public purpose and mission. Public research universities can afford to focus on specific state needs and, as in the case of UMass, typically have a presence across regions in the state. Strong private university research activity does not substitute for having a strong public university research presence.

Fourth, Massachusetts needs to promote technology collaborations. Even with funding available, they need to be facilitated. An excellent example is CIMIT—a highly successful strategic alliance of Partners HealthCare System, MIT, Draper Labs and industry affiliates. CIMIT has learned that the participation of partners requires active support. Not only does CIMIT have managers in key areas of research and product development focus, but at each of its partner organizations, it has a "site minder" to help identify opportunities and to get researchers involved.

Fifth, matching funds is a powerful concept to leverage resources as well as measure success, but **capacity building** is also essential. There is often a the need for a lead investment to establish capacity to build on a new opportunity or to grow an established field to take advantage of new technology developments.

Sixth, active efforts must be made to leverage and complement the strong research base of private university and teaching hospitals, in collaboration with UMass.

Seventh, innovative mechanisms for collaboration are required. Sustaining a new culture of technology partnerships and strategic alliances is a long-term endeavor and calls for involving industry, higher education and government in steering and coordinating. Strategic assessments must be regularly updated, new opportunities and changing environments evaluated and future strategic investments vetted. This cannot occur without a broad-based coalition effort that can stand over time.

Specific new roles and responsibilities for each of the stakeholders flow from this shared understanding of what it takes to succeed.

For Massachusetts to succeed in meeting the challenges it faces in science and technology competitiveness, the key stakeholders will need to work together in new ways.

State government

The state needs to:

- Offer matching investments for securing federal government research grants.
- Support UMass to become a leading public university research system with focused programs to address state needs.
- Ensure a talent generation and retention effort recognizing the importance of a broad spectrum of skills development in core technology areas, including technicians generated at the community college level through graduate degrees for high level scientists and engineering talent.
- Ensure the pipeline of future workers through ongoing support for K–12 science, technology, engineering and math (STEM) skills.

- Recognize the need for support funding for facilitation of strategic alliances.
- Create incentives for industry collaboration with universities.
- Invest in technology connecting initiatives, not just research initiatives. Key efforts such as incubators, proof-of-concept funding and commercialization assistance require state support.
- Ensure all regions of the state are served, perhaps through establishing a technology development mandate for the Regional Competitiveness Councils.
- Recognize the need for private industry involvement to sustain success.
- Measure success—take a long-term view focusing on new research and investments generated and jobs created.

The private sector

The industry associations across Massachusetts need to:

- Come together and take responsibility for identifying key needs and priority areas in research and development for the state.
- Actively engage their membership in seminars and orientations to identify opportunities and, for specific initiatives, find champions willing to help define the problem in concert with research faculty.
- Reach out to Massachusetts universities.
- Promote industry co-investments in specific opportunities and initiatives.

The University of Massachusetts

UMass needs to:

- Be a catalyst for regional economic development across its campuses, building specific research capabilities suited to the regional economic base, supporting product development activities and providing needed specialized talent.
- Pursue research and talent generation in areas of strategic significance to the state's overall technology industry base.
- Actively seek broader multi-institutional partnerships with private universities in Massachusetts, leveraging strengths from private universities for regional development across the state.
- Promote more in-state licensing and new business formation as priorities for technology commercialization.
- Develop one-stop clearinghouse capacity to work with industry.
- Utilize its leadership role in the Mass Technology Transfer Center to promote stronger ties with private universities and industry.

Private universities and teaching hospitals

Private universities and teaching hospitals need to:

- Be at the table with industry, UMass and government in formulating strategic priorities and guiding investment decisions.
- Pursue multi-institutional approaches that leverage Massachusetts' capacities and create new competitive advantages.
- Participate in efforts to promote industry outreach and liaison activities.

Economic Driver One:

Leverage Massachusetts' breadth and strengths by promoting multi-institutional strategic initiatives that reach not only across universities, but also among universities, industry and government—nine strategic alliance opportunities identified for ongoing discussion

Not all states are built alike in technology, and it is the differences in a state's technology portfolio that can best define how a state can succeed in technology-based economic development. States are learning that to gain economic value from their research base they need to assess their specific areas of research focus and excellence found across universities and industry, particularly those that offer platforms to industries of the future.

The purpose of this technology road map is to go beyond analysis and think boldly and broadly across Massachusetts' core technology focus areas to identify specific areas for future strategic alliances and collaborations across its university, teaching hospital and technology industry base. The goal is to translate the core technology focus areas found in Massachusetts—which represent a critical mass of skills and know-how—into opportunities for Massachusetts to gain a leading position in emerging technologies and to capture those emerging technology strengths into innovative new products and companies.

Massachusetts is unique in the national leadership and local economic impact of its private universities and teaching hospitals. These institutions have helped build the modern Massachusetts technology-based economy, and are essential to the state's future competitive advantage. Supporting alliances that draw upon the expertise of these private universities and teaching hospitals, as well as adding to their capabilities, is critical for advancing Massachusetts' national research leadership and ability to compete for the production jobs of the future.

One type of strategic alliance opportunity is major new multi-institutional, multi-disciplinary research centers, often with "go to" signature facilities, typically drawing on federal funding or major industry consortiums. These are referred to as mega-projects, intended to enable the state to gain recognition as a technology leader, recruit significant numbers of new faculty and researchers, and be a key generator of future talent pools, while serving as a platform for broader industry-university collaboration.

Through in-depth interviews and follow-on outreach, nine possible opportunities for strategic investment by stakeholders in Massachusetts have been identified. **While these opportunities are significant and promising, it should be kept in mind that they are not exhaustive.** The goal in presenting them is to demonstrate the range of opportunities available to Massachusetts and to help inform approaches for realizing these opportunities *(see Table 9)*. Each should be the subject of a further due diligence study to determine its feasibility, including how best to leverage existing state match funds to secure the more substantial federal and private commitments that would be required.

These opportunities offer a portfolio of options for Massachusetts. Importantly, these options demonstrate:

- The **interdisciplinary** nature of major opportunities in emerging research areas. These major opportunities typically draw upon a number of the core technology focus areas found in Massachusetts.

Nine Strategic Alliance Opportunities

1. Nanoscale device fabrication facilities network
2. Smart materials technology incubator
3. Neuroscience systems biology consortium
4. Biogrid
5. Next generation sensing and imaging testbed
6. X-ray laser facility for next generation imaging
7. Integrated communications-IT platform for emergency response and command control
8. Industrial biotechnology and related technologies
9. Ocean exploration and management R&D consortium

- The relevance to a broad **cross-section of Massachusetts industry**. These nine opportunities are expected to engage a range of key industries in Massachusetts. Massachusetts has the luxury of a diverse industrial economy and should take full advantage of many possible drivers of future growth.
- The **regional** nature of technology opportunities in Massachusetts. All regions of the state are included in at least one of these major research center opportunities.
- A **range of payoffs**. Across the nine major research center opportunities some are more near-term and some longer term. Many have different stages to their development. This promises Massachusetts a pipeline of development prospects with potential payoffs ranging from the relatively short-term to more distant prospects.

Nine strategic university-industry alliance opportunities: Highlights*

Nanoscale Device Fabrication. Massachusetts has the opportunity to be a leader in the transition to nanoscale fabrication of devices from new electronic systems to medical devices to drug delivery systems. The state enjoys broad university research strengths in key fields, major R&D commitments by the electronics industry in the state and users in the biomedical field, a leading application area for nanotechnology. What Massachusetts is missing is an integrated approach that will promote collaboration and the greatest access to industry across facilities. Massachusetts must be seen as offering not just a collection of world class facilities in nanotechnology, but an integrated infrastructure of R&D support to the range of companies that would pursue the fabrication of nanoscale devices and systems.

Smart Materials. Massachusetts has an opportunity to be at the forefront of smart materials development involving new on-body sensors, more durable, weather-resistant clothing, lightweight power supply systems and much more by leveraging the R&D, unique research facilities, and extensive university and industry relationships of the Soldier Systems Center (SSC) at Natick. The state can play a key role in providing the support needed in the early stages of technology development in the case of commercially promising technologies and applications outside the scope of the SSC's mission. For instance, the state, together with the locality, can support the creation of a business incubator linked to the SSC that provides a range of business services to firms pursuing business opportunities in advanced materials emerging not just from SSC activities but more generally.

Neuroscience Systems Biology Consortium. Massachusetts could become a leading center for neuroscience systems biology, focusing on signal pathways research in the brain to position the state for development of neuroscience therapeutics and interventions. A major centers initiative developed as part of the NIH's recent Technology Roadmap, as well as funding available through NSF's Integrative Biology and Neuroscience program offers Massachusetts the opportunity to draw together its extensive university resources in the neurosciences and neurology and to engage industry more effectively in pursuing a range of possible biomedical applications. This initiative could be a platform for a range of commercial development efforts by biotechnology, medical device, and pharmaceutical firms based in Massachusetts.

These nine strategic alliance opportunities are presented in detail in the companion publication "Strategic University-Industry Alliance Opportunities"

Biogrid. Massachusetts has an opportunity to set the pace in biomedical research and telecommunications infrastructure technologies through developing a specialized "biogrid" infrastructure. Biogrid would be a cutting-edge IT infrastructure enabling

Table 9: Portfolio of Nine Strategic Opportunities

STRATEGIC ALLIANCE	CORE TECHNOLOGY FOCUS AREAS DRAWN UPON	INDUSTRIES AFFECTED	REGIONS AFFECTED
Nanoscale Device Fabrication Facilities Network	Advanced Materials Sensing, Optical, Electro-mechanical Devices Life Sciences	IT Telecom Biotech Medical Devices Advanced Manufacturing	Greater Boston Northeast Pioneer Valley
Smart Materials Technology Incubator	Advanced Materials	Medical Devices Advanced Manufacturing	Greater Boston Northeast Southeast Pioneer Valley
Neuroscience Systems Biology Consortium	Life Sciences Computer Sciences	Biotech Medical Devices	Central Greater Boston Pioneer Valley
Biogrid	Computer Sciences Life Sciences	IT Telecom Biotech Pharmaceuticals Health Care	Central Greater Boston Pioneer Valley
Next Generation Sensing and Imaging Testbed	Sensing, Optical, Electro-mechanical Devices Signal Processing Computer Sciences	IT Telecom Biotech Medical Devices Advanced Manufacturing	Central Greater Boston Northeast Pioneer Valley Berkshire
X-ray Laser Facility for Next Generation Imaging	Advanced Materials Genomics and Proteomics	Electronics Biotech Materials	Greater Boston Central Pioneer Valley
Integrated Communications-IT Platform for Emergency Response and Command Control	Signal Processing Computer Sciences Environmental Science	IT Telecom Defense	Central Greater Boston Southeast (ports) Pioneer Valley Berkshire Cape and Islands
Industrial Biotechnology and Clean Technologies	Advanced Materials Environmental Science	Advanced Manufacturing	Greater Boston Northeast Southeast Pioneer Valley Cape and Islands
Ocean Exploration and Management R&D Consortium	Life Sciences Environmental Sciences Computer Sciences Sensing, Optical, Electro-mechanical Devices	Biotech Fisheries Environmental	Greater Boston Southeast Cape and Islands

unique communications and computing capabilities in the region. This infrastructure would more effectively link extensive university resources and industry in key fields. The collaboration, enabled by a Biogrid, offers to make R&D substantially more efficient, greatly reducing drug research costs and making Massachusetts a uniquely attractive site for pharmaceutical R&D. A key source of support for this initiative would come from the NIH, which funds multi-institutional, multi-disciplinary National Centers for Biomedical Computing that undertake next-generation computing, visualization and software applications to derive the value of large scale, heterogeneous genomics and proteomics databases.

Next Generation Sensing and Imaging. Massachusetts can capitalize on the coming "sensor revolution" by drawing together its vast, yet poorly coordinated cluster of capabilities in sensing and imaging spread across Hanscom, universities, teaching hospitals, federal labs, and industry. One important way to begin to link and focus these capabilities is to develop a unique test bed facility that goes across the full range of sensors from infrared to microwave to RF to ultra-violet, as well as to consider a series of signature facilities pursuing leading-edge applications.

Other related opportunities are suggested for a pathblazing X-ray laser facility and the competition for Centers of Excellence by the Department of Homeland Security. Individual, more focused opportunities are discussed immediately below:

"Go To" X-ray Laser Facility for Next Generation Imaging. Establish a unique leadership position in next generation imaging technologies by establishing a one-of-a-kind large national user "X-ray laser" facility. This facility, which will offer the revolutionary capacity to observe phenomena at the molecular level in real time, will provide a key resource to the growing field of biotechnology. This will also be a resource for pharmaceutical companies interested in genomics and proteomics, and companies involved in nanotechnology-related materials development, many of which will be new start-ups in Massachusetts. A bid on this next-generation facility would be led by MIT, with its strong scientific capacity in accelerator and laser technologies. Although a leading contender for this facility, MIT faces competition from at least two powerful institutions outside Massachusetts, including Stanford, which is currently slated for DOE funding for a limited demonstration facility of X-ray laser capability, and Argonne National Lab, a major facility that has added new generation facilities over time with the active support of the state of Illinois.

Integrated Platform for Emergency Response Systems and Command/Control. Create a unique capability related to Homeland Security and Command/Control defense needs by building on established strengths in remote sensing and detection, computer networking, communications and pattern recognition in order to develop a next generation platform for integration of emergency response systems and command/control defense systems. This initiative would leverage the extensive base of defense-related IT and communications activities found at Hanscom, MITRE, Lincoln Labs and the strong base of defense contractors in Massachusetts.

Industrial Biotechnology and Related Technologies for Next Generation Technology Development, Demonstration and Validation. Industrial biotechnology and related technologies, such as green chemistry and bio-nanotechnology, affords the potential of significant benefits for advancing industrial activity in Massachusetts. It offers the potential to create new high value-added products that are environmentally friendly and reduce the risks of terrorism to industrial facilities, particularly for chemical plants. The growing opportunities in industrial biotechnology can draw on the research expertise in cross-cutting technologies in Massachusetts, including nanotechnology, materials science, green chemistry, and microbiology, among others. Key to advancing next generation products and processes of industrial biotechnology and related technologies is having specialized facilities for development, demonstration and validation.

Ocean Exploration and Management. This is an emerging area of research focus for the federal government. In a recent report, the National Research Council, a bellwether of future federal R&D investments, has called for a large-scale, integrated program of ocean exploration. A major justification for this program is the opportunity for unique applications of new capabilities such as remote sensing, advanced data storage, mining and analysis, and remotely operated vehicles. This program could provide a platform for Massachusetts' universities and industry to pursue leading edge developments and markets in these fields, in which Massachusetts' institutions have traditionally been strong.

Considerations in Identifying Strategic Alliance Opportunities

1. Assessment of core technology strengths in Massachusetts. In essence, core competencies represent "critical mass" of know-how. It is from core competencies that gaining a position in emerging technologies can best be realized. Otherwise, emerging technology fields that are untied to core competencies require starting from scratch with major investments, rather than leveraging existing strengths.

2. Availability of federal R&D funding in each technology field. This can provide the basis for expanding university R&D capacity and drawing industry participation in university research programs. More specifically, federal support for research centers is sought. Center programs offer the level and duration of support necessary to draw together multidisciplinary teams of researchers needed to advance work in a field and effectively address problems of interest to industry.

3. The real prospect of linkages to industry active in Massachusetts. Connections to Massachusetts-based firms offer an important potential pathway to economic development in Massachusetts. However, potential opportunities were not considered narrowly in terms of connections with Massachusetts-based companies. Connections with industry are important more generally. Existing companies offer access to a range of relationships to other firms and organizations that may prove vital to commercialization. For example, many new technologies are often best commercialized by specialized firms, who may not be members of a consortium initially. Also, established firms may play an important role as early customers and sources of capital to start-ups formed around new technologies developed at the university.

4. Economic impact. The goal was to focus resources on the opportunities with the greatest payoff potential. Assessments involved a mix of public information on private market forecasts and expert interviews.

Economic Driver Two:

Initiate "connecting" industry application-oriented activities—five initiatives identified for ongoing discussion.

Beyond advancing Massachusetts' technology leadership in emerging areas through major research centers, it is crucial that Massachusetts ensures that its research base is "connected" to growing and sustaining industries in the state. As one leading industry executive explained, "the goal of identifying opportunities for research investment is not to increase the level of research funding, but to capture the economic benefits for Massachusetts from these research investments."

Translation of research activities into tangible economic activities can be facilitated by more focused technology development activities—typically emphasizing more applications development. These activities can address gaps in the process of translating research activities into commercial products for specific areas—such as leading states are doing for pre-commercialization assistance and pre-seed capital. Or they can enable greater interaction and networking for specific technology areas across the base of university, non-profit and industry activities.

These technology connecting activities usually require upfront state investments to catalyze the process. Cost sharing or matching is a good measure of success, along with newly-stimulated economic activity.

Five technology connecting initiatives: Highlights*

Life sciences

The substantial base of life science research activities in Massachusetts, along with a growing industry presence, most notably in biotechnology, medical devices and increasingly in pharmaceutical companies, makes this an area ripe for future development. While it is often noted that there are close connections between basic research discoveries and future product development, the hurdles in translating life science research discoveries into commercial products speaks to the need for specific technology connecting activities.

At one level is the challenge facing teaching hospitals and university bioscience research efforts across the state—how to take promising basic life science research discoveries that identify targets for new drug therapies through the initial stages of drug discovery and development. As part of the corporate outsourcing of research activities, such as initial screening against libraries of drug candidates, the pharmaceutical industry is attempting to reduce its risks by actively pushing more of the initial drug discovery activities on its potential university partners. At the same time, venture capital firms are reluctant to invest in uncertain biological targets.

At another level, capturing the manufacturing activity of innovative new "biotechnology" therapies—such as protein therapeutics—is a challenge. In Massachusetts, there is a strong base of emerging biotechnology companies, but they lack the staff and technical resources for the complex process of biopharmaceutical manufacturing. A recent Massachusetts' Biotechnology Council study, prepared by Boston Consulting Group, found that only 10 percent of the state's biotechnology companies are currently involved in manufacturing. As these emerging biotechnology companies advance their product ideas, Massachusetts needs to be prepared to have the expertise and facilities to capture these manufacturing activities.

Five Technology Connecting Initiatives

Life Sciences:

1. **Statewide bioscience therapeutic commercialization**
2. **Bioprocessing consortium**
3. **Statewide industry/university networks for medical devices**

Information Technology and Communications:

4. **Northeast educational and research network**

Advanced Manufacturing:

5. **Statewide product development centers**

**These five technology connecting initiatives are presented in detail in the companion publication "Strategic University-Industry Alliance Opportunities."*

Medical devices technology offers its own challenges. It is not well-recognized, but academia is often a critical element for advancing medical device products. Clinicians are key for identifying needs and opportunities, while engineering and scientific research capabilities found in academia are important resources for a medical device industry which is comprised of many smaller companies, with niche market opportunities. As the industry data reveal, the biomedical device industry in Massachusetts is significant, and one well-positioned for continued growth. While Boston is recognized for its biomedical device presence, the medical device industry is also a key area of opportunity for Western Massachusetts, Central Massachusetts, and Southeast Massachusetts.

To address these challenges three technology development initiatives are proposed:

A statewide bioscience therapeutic commercialization entity focused on conducting market opportunity assessments, supporting initial screening for likely drug candidates and providing follow-on pre-seed investments in pre-clinical testing, including animal testing, as well as support for initial Phase I and II clinical trials.

A bioprocessing consortium in Massachusetts that can focus on developing pre-zoned areas for biopharmaceutical production activities, with a focus on regions of the state that are more cost-competitive; providing Good Manufacturing Practices (GMP) training, building upon the base of efforts underway across universities in Massachusetts; and guiding state investments in contract manufacturing facilities.

The expansion and linkage of academic/industry networks across the state that bring together clinical expertise with technical and engineering knowledge to support new product development and firm formation for the medical device industry. In the Greater Boston area, for example the highly regarded and well-established Center for Integration of Medicine and Innovative Technology (CIMIT) has encouraged collaboration between the academic and industry sectors to expedite the development of new medical technologies. In Central Massachusetts and Western Massachusetts emerging academic/industry networks are developing led by the WPI Bioengineering Institute and the new Bio Economic Technology Alliance involving Baystate, UMass and BEACON. On a state-wide basis, MassMEDIC, the Massachusetts Medical Device Industry Council, has continued to showcase the academic resources and research capabilities of area institutions and academic health centers.

Information technology and communications

There is a critical need in Massachusetts to provide a network to enable high performance grid computing activities that connect across universities, teaching hospitals and industry in the state and to the broader New England and Northeast region. In recent years, many local fiber optic rings or loops have been constructed to provide the internal digital connectivity for various universities and in some cases linking several universities together in a collaborative network. In Massachusetts, these rings are confined to specific geographic areas like Amherst, Worcester, and Boston.

These rings comprise the infrastructure that allows advanced research and computer applications requiring greater bandwidth for high speed connectivity to function within a respective institution and through the Internet. Connecting these rings can facilitate broader-based grid computing (a software and hardware infrastructure which functions on top of a conventional network) that can enable interconnection of heterogeneous devices and delivery of new classes of services.

For instance, Massachusetts and all of New England is not currently planned to be served by the new $100 million optical network called National LambdaRail offered by an academic consortium including Atlanta, Chicago, Denver, Jacksonville, Pittsburgh, Raleigh, Seattle, Sunnyvale, CA and Washington, D.C. This consortium is developing an infrastructure for experimental research on optical networks and other types of advanced scientific, engineering and medical research.

Massachusetts has a broad base of industry focused on telecommunications, in which a grid computing test bed can be of particular importance for optical networking as well as for wireless grid technologies. Furthermore, having a developmental and testing grid computing environment can be of value to companies engaged in developing new computer networking and data storage/retrieval services as well as addressing cybersecurity issues, such as intrusion. Finally, grid computing is of key importance as genomics and proteomics advance. It offers the opportunity to provide the platform for developing informatics software, middleware and data management for the large scale, heterogeneous data that underlies modern biotechnology.

A Northeast Research and Educational Network is being proposed that can provide a platform for advancing high performance grid computing across Massachusetts, and create important linkages of Massachusetts to other networks. Additional resources will be needed to provide specific types of test beds and research platforms. Opportunities for funding from key federal agencies is possible based on the specific application and the broad breadth of institutions that can be linked together.

High value manufacturing partnerships

The analysis of core focus areas suggests that there is a substantial base of advanced materials and electro-mechanical devices (instruments, controls, sensors and mechatronics) in Massachusetts, owing to the state's historic emphasis on precision machining and, more recently, systems integration. A key question for Massachusetts is how to support these still significant industry drivers with the needed upgrading of process and products and remain competitive.

Technical support for advancing near-term manufacturing activities is not a mainstay of the major research universities in Massachusetts. More isolated, specific initiatives have been undertaken, such as UMass Lowell's Institute for Plastics Innovation, WPI's Metal Processing Institute, the Boston University Photonics Center, and the UMass Dartmouth Advanced Technology and Manufacturing Center.

Establish product development centers across the state affiliated with regionally-based universities that would function as independent, contract applied research and technology problem-solving organizations. These product development centers would be staffed with industry experienced engineers and scientists, but would also reach out to faculty and students for specific project work. The primary focus of the product development centers would be to respond to industry needs, but they would also provide faculty another resource they can effectively use to secure federal, industry and foundation funding. Consideration should be given to co-locating with the Product Development Center, with a university-driven commercialization fund and a campus-affiliated technology incubator, similar to other universities throughout the country. In addition to operating support, which would be partially offset by fees earned from industry customers, each product development center should have one-time funding to invest in equipment, pilot plants, and design labs in their specialty focus areas.

Economic Driver Three:

UMass and Regional Economic Development

The University of Massachusetts system is the state's most significant public technology development investment, with direct state funding reaching nearly $400 million in operating and capital support.

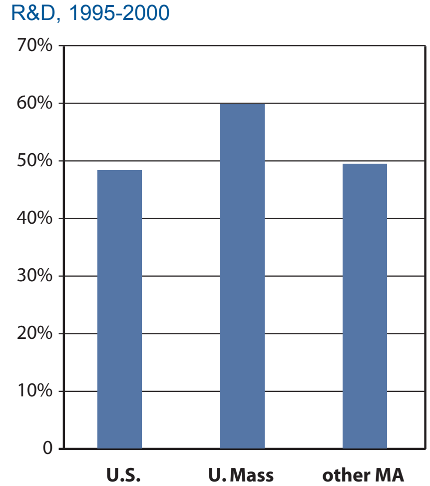
The mission of the UMass system speaks directly to the improvement of the state's economic competitiveness and embraces a strong public purpose. In addition to the traditional role the UMass system and public higher education in general has played in providing affordable access to post-secondary education, there are two other primary economic development roles of UMass:

- One is to provide an economic engine particularly for those regions outside the Greater Boston area, especially in workforce development supporting and complementing community colleges and state colleges;
- The second is serving as the leading state investment to establish specific research capabilities and to facilitate strategic alliances with private higher education and with industry to promote the state's national research leadership and competitiveness for production jobs of the future.

But Massachusetts has been quick to cut support for the UMass system and all of public higher education in difficult fiscal times, and has never given it the broad technology development mandate provided to public universities in New York, California, Pennsylvania, North Carolina and other key competitor states. Not surprisingly, Massachusetts has relied to heavily on its private universities and now finds itself at an increasingly competitive disadvantage. As a result, Massachusetts has not captured the economic development we otherwise might have seen across the state.

Despite its relatively smaller size, UMass research growth outpaces all U.S. universities and private universities in Massachusetts.

Table 10: Percentage growth in university R&D, 1995-2000



Source: National Science Foundation, calculations by Battelle

Massachusetts can turn this situation around, as other states have done. It will take a fiscally prudent, ten-year plan tied to targeted investments relating to core technology focus areas critical to fueling economic growth statewide and in specific regions. The UMass system has, in fact, done well with its available resources, and is prepared to move forward as a growing asset to partner with industry and with the state's private universities and teaching hospitals.

UMass has earned the right to say it is a good investment for the state. It provides growing returns in research. It drives technology capacities across the state. And it is a major generator of talent that overwhelmingly stays in the state.

Consider the facts:

A Fast Growing Research Engine for Massachusetts: The UMass system is a relatively young university and is still in a growth phase. The UMass system now stands at approximately $300 million in funded research—the third largest research university in the state behind Harvard and MIT. Over the 1995 to 2001 period (most currently available for all universities), the UMass system significantly outpaced the growth across universities nationally—60 percent versus 48 percent—and outpaced private university research growth in Massachusetts as well *(see Table 10)*.

The Leading Technology Driver Across Regions of the State: As the third largest research university in the Commonwealth, the UMass system is by far the largest university research institution for the state outside the Greater Boston region. UMass comprises two-thirds of the university research outside of the Greater Boston region, including research conducted at Woods Hole and Worcester Polytechnic Institute. More than 95 percent of the UMass system research activity, or $280 million, takes place outside of the Greater Boston region. UMass is the key research driver for ensuring all regions of the state enjoy the benefits of technology development.

A Prominent Generator of Talent for Massachusetts: The UMass system is key to generating science and engineering graduates, particularly those that seek to stay in Massachusetts. UMass generates well over 2,500 graduates in science and engineering degree programs annually. Even more importantly, nearly 85 percent of the Massachusetts residents who graduate from UMass remain in Massachusetts. So it truly is the key institution driving talent production in the Commonwealth.

It is important to note that without a rising research competency, and the faculty and graduate students it requires to conduct that research, UMass cannot generate the specialized talent pools required to support the state.

UMass needs to be "right-sized" through growth in targeted, strategic areas of focus—a goal of $600 to $800 million in funded research by 2014.

The idea that UMass can be a key driver for linking Massachusetts' great private university and industry technology strengths is not a pipe-dream, but a growing reality.

Despite the fast growth of research at UMass in recent years, there is a considerable distance to go for UMass to reach the stature of its key public university competitors. If ranked as an overall university in research funding, the UMass system would rank only 42nd in the nation—and behind four of the separate campuses of the University of California system. UMass, with $300 million in research funding, stands at roughly half the size of the public university systems in North Carolina and New York, and one-third that of Pennsylvania.

And those are states which also have leading private universities. New York has Columbia, Cornell, University of Rochester and Rensselaer Polytechnic Institute. Pennsylvania has the University of Pennsylvania, Carnegie Mellon University and Lehigh University. California has Stanford, University of Southern California, and CalTech, while North Carolina has Duke and Wake Forest.

Massachusetts needs to make a long-term commitment to the UMass system, in which the system is held accountable for performance, but is ensured predictable, steady growth in its annual operating budget. The goal should be to support targeted, strategic investments in the UMass system to advance capabilities in core technology focus areas and in areas of strategic opportunities. The most appropriate funding vehicles appear to be matching grants for endowed chairs and capital facilities. The UMass system should reach $600 to $800 million in annual funded research by 2014 through these targeted investments. The majority of this new funding will come from increases from federal, industry and other non-state funding sources. It is expected that there will be a $3 return in research funding for every one dollar invested by the state in UMass. But the state will need to be an upfront investor, primarily supporting the recruitment of eminent scholars and the build-out of associated research facilities. That the state will need to sustain an annual increase in funding of $50 million to $75 million across operating and capital funding to reach the goal of growing targeted areas of research so that UMass reaches $600 to $800 million in research funding by 2014. At the same time, specific reforms to the construction and design processes are needed—or at least an exemption for UMass research facilities.

Quick Snapshot of the UMass System

Formed in 1992, the UMass system is one of the youngest state university systems in the nation.

It has five research campuses:

UMass Amherst, a flagship campus, with total research funding reaching $109 million in FY 2002. Key strengths found in computer science, polymers, communications, cell and development biology, neurosciences and chemical engineering. Thanks in part to state support, Amherst recently won a $40 million NSF Engineering Center for sensor technology.

UMass Boston, a young campus, building a strong national reputation in the environmental sciences. Research funding reached $13 million in FY 2002.

UMass Dartmouth has experienced rapid growth in its research base, which reached $15 million in FY 2002. Specific areas of research gaining national recognition include marine science, textile sciences and botulism research.

UMass Lowell, enjoys a research base of over $22 million, with a concentration in the material sciences, including plastic processing and nanotechnology. A wide variety of activities in biomedical arena, including a bioprocessing center, drug delivery and nutraceutical testing. Specific niche in submillimeter wave technology.

UMass Worcester is a fast growing medical school, outpacing national growth in NIH funding from FY 1996 to FY 2002. Total research funding was $133 million in FY 2002. Major research discovery in genomics involving RNA interference-cited as #1 research breakthrough by *Science* magazine-and strengths in microbiology and immunology led to recent NIH award as one of five national centers in human immunity and biodefense. The Mass Biologic Laboratories, a specialized unit of the UMass Medical School, is a leader in vaccine development and research on monoclonal antibodies.

Economic Driver Four:
State Coordination and a Public-Private Compact

Massachusetts state government is to be applauded for the first significant investment in Massachusetts broad science and technology capacities in many years through the recent economic stimulus package and matching grant funding. At the same time, the private sector, through the broad alliance of industry, universities, teaching hospitals and economic development organizations participating in the Science and Technology Initiative organized by Mass Insight, has also made significant advances, including this technology road map and strategic alliances study.

A key risk for Massachusetts as it goes forward in its future investments in strategic alliances, technology connections, and building the capacity of UMass is that these investments will be managed as isolated activities, more piecemeal than part of a broader plan for how Massachusetts coordinates its economic development.

There is a particular need for coordination of state strategies led by the Governor and the Department of Business and Technology. Several state agencies and quasi-public organizations will have responsibility under the recent economic stimulus legislation to advance science and technology initiatives. Having these organizations work together with a common game plan is critical to capture the value-added of integrated program activities for specific target opportunities.

There is also a need to bring together Massachusetts industry, public and private universities, teaching hospitals and government in a Compact that can serve as a forum for discussing science and technology needs and initiatives. This Compact can help set goals, identify emerging opportunities, and track progress. There is an opportunity for this compact-type approach to support developing multi-disciplinary, cross-sector committees in strategic technology areas—such as nanotechnology fabrication or advanced software, IT and communications systems or bioinformatics—to take advantage of specific expertise to help inform state science and technology initiatives. Another important need that the Compact can serve is to have all science and technology stakeholders working together on a Massachusetts agenda for federal research funding, particularly to protect and expand key facilities, such as Natick Army Lab and Hanscom Air Force Base.

The Massachusetts Technology Road Map and
Strategic Alliances Study

Appendix:

Core Technology Charts—Competitive and Regional Analysis

Glossary of Terms

Data Sources

Massachusetts' Ranking in Core Technology Focus Areas

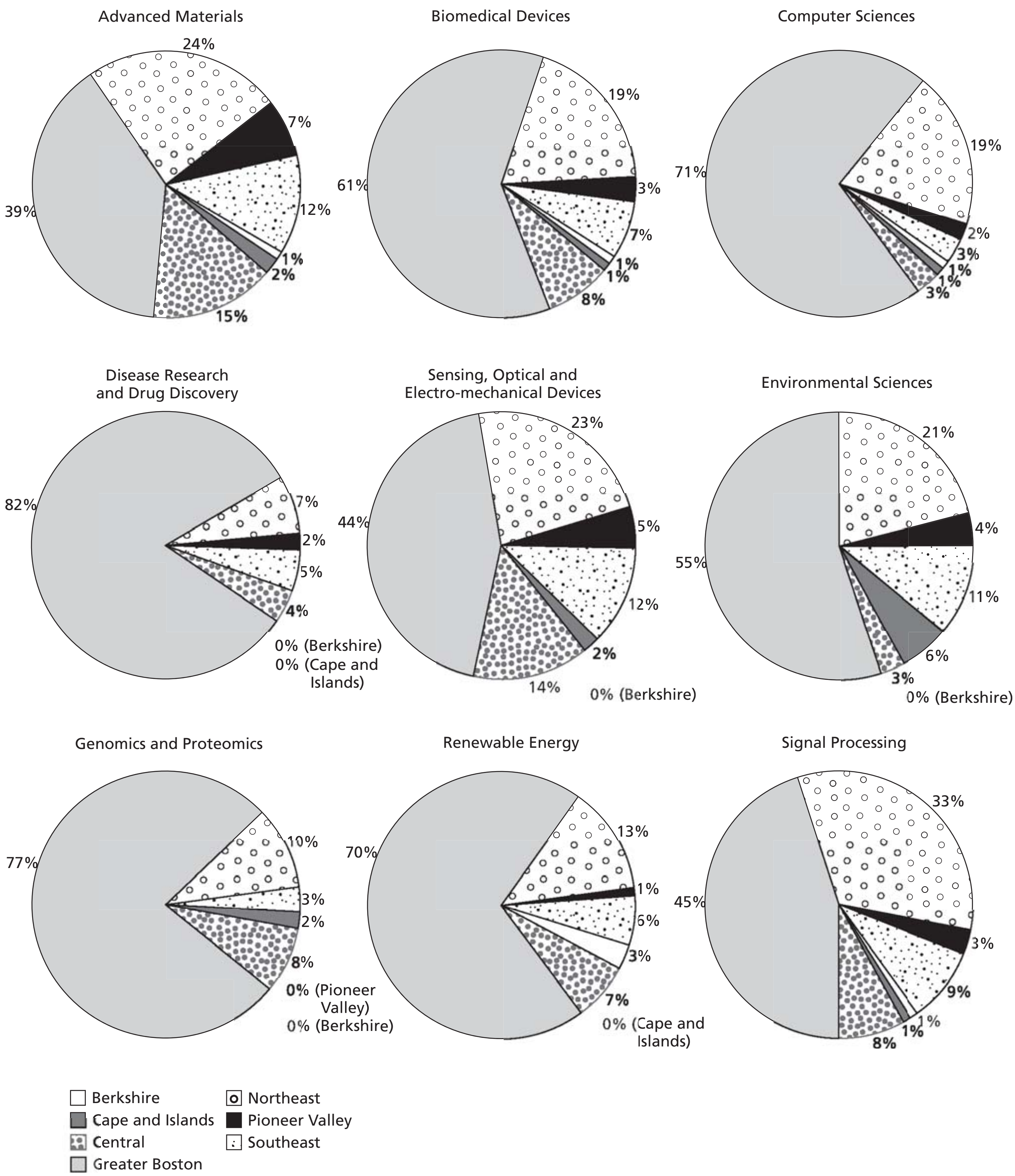
Summary of Massachusetts Position in Core Focus Areas Across Industry, Talent and Research Measures: State Rankings

	INDUSTRY PRESENCE		TALENT GENERATION		RESEARCH EXCELLENCE	
	Number of firms	Employment controlled by Massachusetts firms	Total degrees awarded, 2001	Change in degrees awarded, 1996 to 2001	Total state funding in related-university research fields	Leading institutions in total citations (top 25 in nation) and reputational rankings for related fields
Advanced Materials	◗ 6th	⊖ 12th	◗ 7th	⊖ 36th	◗ 10th in metallurgical and materials engineering	MIT UMass Amherst Harvard
Signal Processing	● 2nd	◗ 8th	◗ 9th	⊖ 17th	◗ 6th in electrical engineering	MIT Harvard
Computer Sciences	● 2nd	◗ 9th	◗ 8th	⊖ 16th	◗ 6th in computer sciences	MIT Harvard UMass Amherst Boston University
Sensing, Optical and Electro-mechanical Devices	● 3rd	⊖ 11th	◗ 8th	⊖ 22nd	● 5th in mechanical engineering	MIT
Environmental Sciences	● 3rd	◗ 10th	◗ 8th	⊖ 38th	● 3rd in earth sciences	MIT Harvard
Genomics and Proteomics	● 2nd	◗ 9th	◗ 7th	⊖ 43rd	N/A	Harvard MIT Tufts UMass Worcester
Disease Research and Drug Discovery	● 3rd	◗ 9th	◗ 6th	⊖ 39th	N/A	Harvard/Partners Boston University Tufts UMass Worcester
Biomedical Devices and Instrumentation	● 2nd	● 4th	◗ 8th	⊖ 38th	N/A	MIT Harvard
Renewable Energy	● 3rd	⊖ 16th	◗ 8th	⊖ 25th	N/A	MIT
Nanotechnology fabrication*	N/A	N/A	N/A	N/A	N/A	MIT Harvard UMass Amherst

Key: Ranking 1–5 = ● **Leader** Ranking 6–10 = ◗ **Challenger** Ranking 11–up = ⊖ **Follower**

- Industry presence based on CorpTech data.
- Talent generation based on National Center for Educational Statistics data.
- Research excellence based on NSF data on university research funding, publications data from Institute for Scientific Information and reputational survey rankings from US News & World Report.
- *Nanotechnology rankings based on recent NSF funding awards under the National Nanotechnology Initiative for top institutions, FY2001–03.

Regional Distribution of Firms in Core Technology Focus Areas*



*Note: Nanotechnology fabrication, as a very early stage technology, lacks sufficient data to support an analysis of industry presence.

ADVANCED MATERIALS

WHAT IS IT? The development of new classes of materials with unusual properties (e.g., strength, wear characteristics, and electromagnetic properties) are expected to open up a broad range of opportunities leading to next generation machines, improvements in product performance and cost, and waste-free products. Typical research activities include the processing of metals, ceramics, and composite materials with a specific focus of working at the nanoscale level.

WHAT DOES IT MEAN FOR MASSACHUSETTS? With a strong concentration in patent and research grant activity, advanced materials is a strong technology thread across industry and universities in Massachusetts. It speaks directly to Massachusetts' long history in plastics, precision machining and textiles, and relates to the state's future as a center for innovative products and emerging industries, from fuel cells to nanoelectronics to adaptive materials (i.e., having properties to monitor health signs, adapt to weather changes, etc.).

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Electronics, medical devices, metalworking, paper converting, plastics, textiles and apparel

EXAMPLES OF INDUSTRY LEADERS:

Cabot Corporation
General Electric
Gillette
Spalding Sports
Nypro
Saint-Gobain

UNIVERSITY LEADERS:

Harvard
M.I.T.
Northeastern
Tufts
UMass Amherst
UMass Lowell
WPI

KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Electronics	Coatings and multi-layer depositions Carbon nanotubes
Medical devices	Biomaterials
Metalworking	Advanced alloys Near net-shape light metals
Paper converting	Coatings and multi-layer depositions
Plastics	Polymer synthesis Processing polymers at nanoscale
Textiles and apparel	Novel material properties for fibers

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Illinois, Massachusetts, Michigan, New York, Ohio, Pennsylvania, Texas

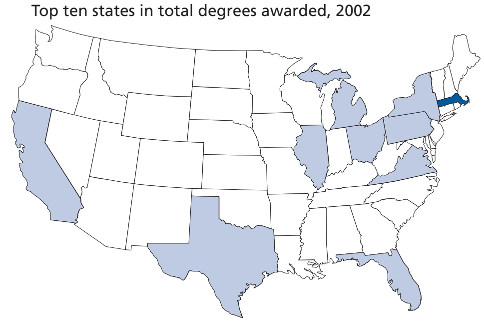
Technology Industry Presence

Top ten states in number of technology firms, 2003

1. California
2. Ohio
3. Pennsylvania
4. New Jersey
5. Texas
6. **Massachusetts**
7. Illinois
8. New York
9. Michigan
10. Connecticut

Talent Generation

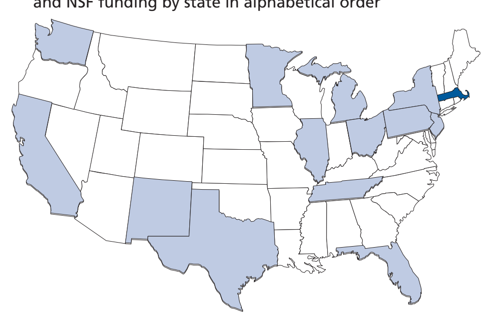
Top ten states in total degrees awarded, 2002



1. California
2. Michigan
3. New York
4. Pennsylvania
5. Ohio
6. Texas
7. **Massachusetts**
8. Illinois
9. Virginia
10. Florida

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order



California
Florida
Illinois
Massachusetts
Michigan
Minnesota
New Jersey
New Mexico
New York
Ohio
Pennsylvania
Tennessee
Texas
Washington

SIGNAL PROCESSING

WHAT IS IT? Signal processing is a foundation technology for communications, computing and embedded systems found in devices. It involves a wide range of activities for transmitting, processing and analyzing signals from audio, video, image, and radar, among other signals.

WHAT DOES IT MEAN FOR MASSACHUSETTS? In Massachusetts, signal processing is a major technology focus of industry, and has a strong concentration in patent activities. Its roots began in the defense industry in advancing the use of radar in World War II, which Massachusetts pioneered, through tracking systems for ballistic missiles during the Cold War to today's information-based warfare activities. Today, signal processing technologies extend extensively into the computer and telecommunications sector. Signal processing also remains a key expertise of major federal defense-related research centers and organizations from Lincoln Labs to Draper Labs to MITRE Corporation.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Defense industries, telecommunications, computer hardware/electronic systems, power systems

EXAMPLES OF INDUSTRY LEADERS:

Analog Devices
Raytheon
Teradyne
EMC
Verizon

UNIVERSITY LEADERS:

M.I.T.
Boston University
UMass Amherst
Harvard
WPI

KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Defense industries	RF technologies Micro-wave technologies
Telecommunications	Wireless communications Digital-analog switching
Computer hardware/ Electronic systems	Digital signal transmission, Amplification, Switching, Embedded network systems
Power systems	Voltage/power transmitters, Switching

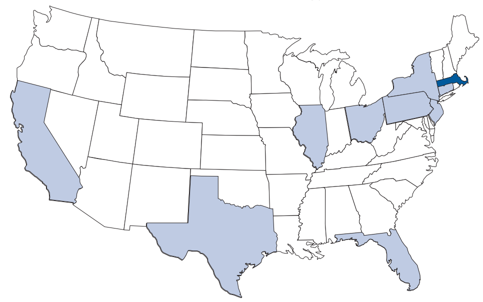
LEADING STATES

(states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Florida, Illinois, Massachusetts, New York, Ohio, Pennsylvania, Texas

Technology Industry Presence

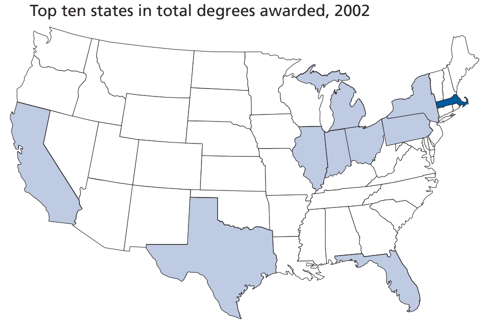
Top ten states in number of technology firms, 2003



1. California
2. **Massachusetts**
3. New York
4. New Jersey
5. Texas
6. Pennsylvania
7. Florida
8. Illinois
9. Connecticut
10. Ohio

Talent Generation

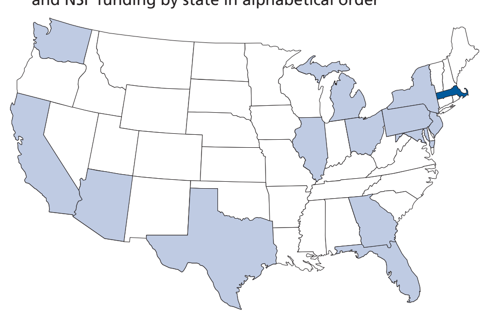
Top ten states in total degrees awarded, 2002



1. California
2. New York
3. Texas
4. Pennsylvania
5. Florida
6. Ohio
7. Illinois
8. Michigan
9. **Massachusetts**
10. Indiana

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order



Arizona
California
Florida
Georgia
Illinois
Maryland
Massachusetts
Michigan
New Jersey
New York
Ohio
Pennsylvania
Texas
Washington

COMPUTER SCIENCES

WHAT IS IT? Computer sciences remains a dynamic, fast-paced technology field involving all aspects of computing from software development to databases to information analysis and retrieval to networking to decision-making and data visualization. Computer sciences is at the intersection of many converging technologies, particularly key for collecting, managing, and interpreting the massive sets of data possible today in fields from genomics and proteomics to supply chain management to financial services.

WHAT DOES IT MEAN FOR MASSACHUSETTS? Computer sciences is firmly rooted in the economic landscape of Massachusetts' technology industry base. As the patent data suggests, there are literally hundreds of firms developing key applications and new computer-related technologies. Massachusetts is also home to a number of leading university computer science research programs found at M.I.T., UMass Amherst, Harvard and Boston University, and is home to many federal research centers and labs focusing on computer science related activities.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Computer services
Defense industries
Health care
Financial services

EXAMPLES OF INDUSTRY LEADERS:

Avid Technology
Cognex
EMC
Raytheon
Verizon

UNIVERSITY LEADERS:

M.I.T.
UMass Amherst
Harvard
Boston University

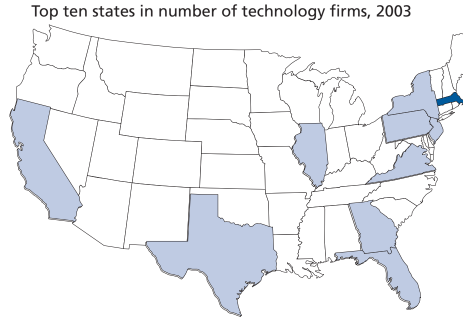
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Computer services	Data storage
Defense industries	Computer modeling and simulation
	Distributed systems
Health care	Computer security
	Computer networking
Financial services	Data mining and information retrieval
	Software applications development

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Illinois, Massachusetts, Pennsylvania, Texas

Technology Industry Presence

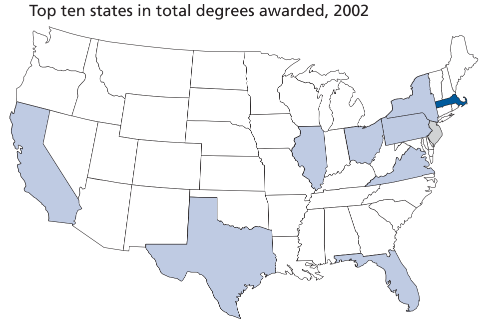
Top ten states in number of technology firms, 2003



1. California
2. **Massachusetts**
3. Texas
4. New York
5. Pennsylvania
6. Florida
7. Illinois
8. Virginia
9. New Jersey
10. Georgia

Talent Generation

Top ten states in total degrees awarded, 2002



1. New York
2. California
3. Pennsylvania
4. Texas
5. Florida
6. Illinois
7. Ohio
8. **Massachusetts**
9. New Jersey
10. Virginia

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order

California
Connecticut
Illinois
Indiana
Maryland
Massachusetts
Michigan
Minnesota
North Carolina
Ohio
Pennsylvania
Texas
Washington

SENSING, OPTICAL AND ELECTRO-MECHANICAL DEVICES

WHAT IS IT? Central to high-tech manufacturing for advanced instruments, machinery and components are a broad set of technologies that enable measuring, sensing, actuation and the fusion of electrical and mechanical systems in ever more miniaturized components.

WHAT DOES IT MEAN FOR MASSACHUSETTS? Massachusetts has a long tradition in precision equipment machining, dating back to the 1800's and evolving over several technology transitions into manufacturing of complex industrial products including computers, telecommunications exchanges and switches, electricity transformers, chip-making machines, electro-medical devices and air traffic control systems. The technology area of sensing, optical and electro-mechanical devices is one of the largest clustering of patents found in Massachusetts, led by industry activity. At the university level, Massachusetts is at the cutting edge of many sensing and optical technologies, as well as an emerging leader in micro-electro-mechanical devices (MEMS) and nanotechnology fabrication.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Industrial machinery, computer and communications equipment, medical devices, defense industries

EXAMPLES OF INDUSTRY LEADERS:

Analog Devices
Boston Scientific
Osram Sylvania
Raytheon
Thermo Electron

UNIVERSITY LEADERS:

M.I.T.
Harvard
Northeastern
UMass Amherst
Tufts

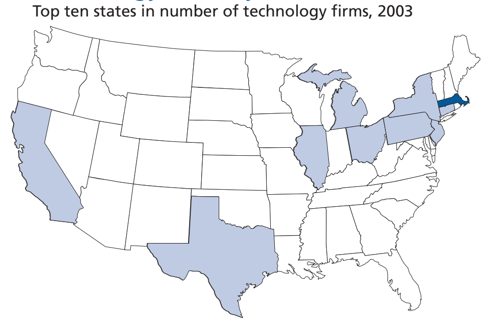
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Industrial machinery	Laser devices Sensors and actuators Gas and liquid flow systems
Computer and communications equipment	MEMS devices
Medical devices	Sensors and imaging devices
Defense industries	Radar systems

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Illinois, Massachusetts, Michigan, Ohio, Pennsylvania

Technology Industry Presence

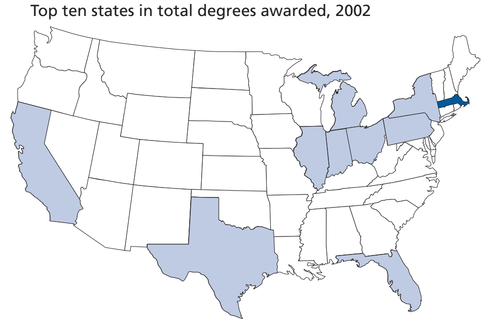
Top ten states in number of technology firms, 2003



1. California
2. Pennsylvania
3. **Massachusetts**
4. New York
5. Illinois
6. Texas
7. Ohio
8. New Jersey
9. Connecticut
10. Michigan

Talent Generation

Top ten states in total degrees awarded, 2002



1. California
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3. Texas
4. Michigan
5. Pennsylvania
6. Ohio
7. Illinois
8. **Massachusetts**
9. Florida
10. Indiana

Research Excellence

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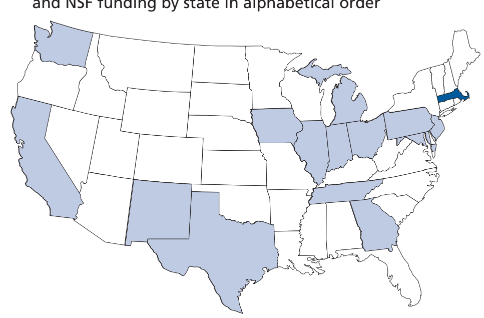


California
Georgia
Illinois
Indiana
Iowa
Maryland
Massachusetts
Michigan
New Jersey
New Mexico
Ohio
Pennsylvania
Tennessee
Texas
Washington

ENVIRONMENTAL SCIENCES

WHAT IS IT? Environmental sciences involve understanding the basic physical and biological processes occurring in marine life and oceanography, ecosystems, climate and earth sciences. Its practical applications range from developing new technologies for detecting and monitoring changes in environmental systems to abating or preventing pollution or generation of toxic chemicals to protecting coastal areas to harnessing the potential of environmental processes for creating new sustainable products.

WHAT DOES IT MEAN FOR MASSACHUSETTS? Environmental sciences represent a critical mass of research activity found across university research drivers and non-profit research institutions in Massachusetts, with a particular emphasis on ocean environmental sciences and climate change. While there is not a cluster of industry-led patent activity found in environmental sciences, there is a growing environmental industry presence. Connecting this emerging environmental industry with the growing base of academic research activities in the environmental sciences can provide a competitive advantage.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Environmental engineering and protection, oceanographic industry, fisheries

EXAMPLES OF INDUSTRY LEADERS:

BOC Edwards
CDM
Clean Harbors Environmental Services
Thermo Electron

UNIVERSITY LEADERS:

M.I.T.
Woods Hole
Harvard
UMass Amherst
Boston University

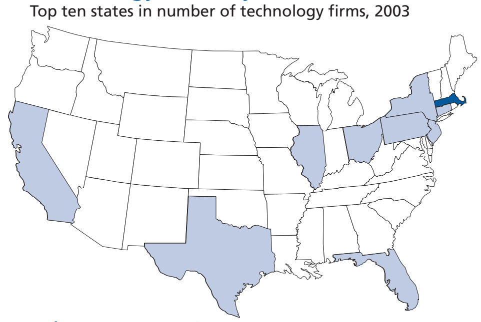
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Environmental engineering and protection	Water quality research Green chemistry
Oceanographic industry (often with strong defense connections for naval activities and increasingly homeland security applications)	Integrated sensing and information systems
Fisheries	Oceanographic and marine science research

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Illinois, Massachusetts, New York, Texas

Technology Industry Presence

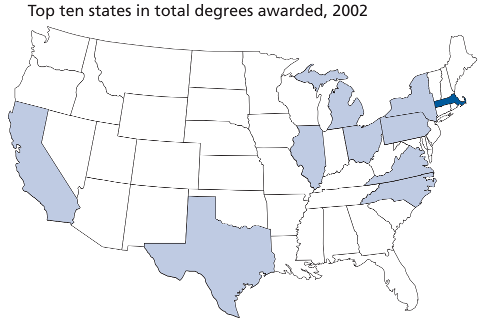
Top ten states in number of technology firms, 2003



1. California
2. Texas
3. **Massachusetts**
4. Pennsylvania
5. Connecticut
6. New York
7. Ohio
8. Illinois
9. New Jersey
10. Florida

Talent Generation

Top ten states in total degrees awarded, 2002



1. California
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3. Texas
4. Pennsylvania
5. Illinois
6. North Carolina
7. Ohio
8. **Massachusetts**
9. Michigan
10. Virginia

Research Excellence

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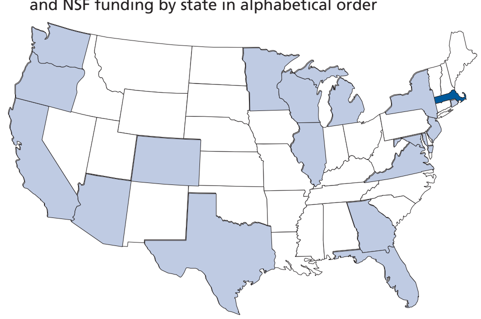


Arizona
California
Colorado
Florida
Georgia
Illinois
Maryland
Massachusetts
Michigan
Minnesota
New Jersey
New York
Oregon
Rhode Island
Texas
Virginia
Washington
Wisconsin

GENOMICS AND PROTEOMICS

WHAT IS IT? Genomics and proteomics involves understanding the structure and function of genes and proteins, holding the potential to identify major new therapeutic approaches to treating diseases. This advanced field of biotechnology represents an area of technology convergence with computational biology and bioinformatics involving the use of advanced, computer-aided modeling, algorithms, pattern discovery, and data mining, visualization and management to infer information about the role of a gene or protein.

WHAT DOES IT MEAN FOR MASSACHUSETTS? The major position of Massachusetts in biotechnology is based on the broad-based strengths found in genomics and proteomics found across industry, teaching hospitals and university research institutions. Having both a strong presence in patent activity and federal research grant activity allows Massachusetts to be well-positioned to take advantage of this fast-paced, evolving field where there are connections between product development and basic research discoveries.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Electronics, medical devices, metalworking, paper converting, plastics, textiles and apparel

EXAMPLES OF INDUSTRY LEADERS:

Genzyme

Millennium Pharmaceuticals

New England Biolabs

Partners HealthCare System

UNIVERSITY LEADERS:

Harvard

M.I.T.

UMass Medical Center

Tufts

UMass Amherst

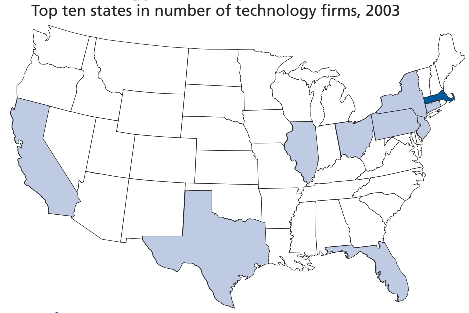
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Biotechnology industry involving broad range of activities from commercial research, diagnostics and new therapeutics development	Bioinformatics
	Gene expression and regulation
	Gene therapy
	Micro-array technologies
Pharmaceutical industry	Protein analysis
	RNA interference (gene silencing)
	Systems biology

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Massachusetts, New York, North Carolina, Pennsylvania, Texas

Technology Industry Presence

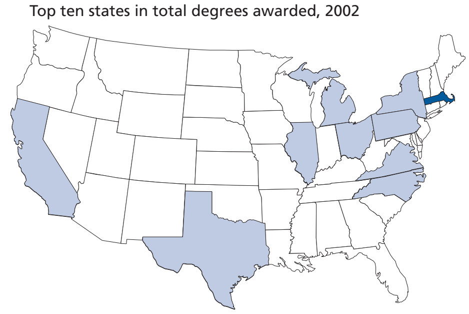
Top ten states in number of technology firms, 2003



1. California
2. Texas
3. Massachusetts
4. Pennsylvania
5. Connecticut
6. New York
7. Ohio
8. Illinois
9. New Jersey
10. Florida

Talent Generation

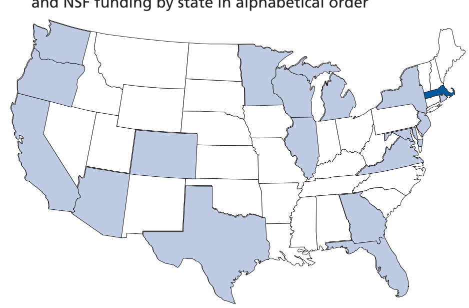
Top ten states in total degrees awarded, 2002



1. California
2. New York
3. Texas
4. Pennsylvania
5. Illinois
6. North Carolina
7. Ohio
8. Massachusetts
9. Michigan
10. Virginia

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order



Arizona
California
Colorado
Florida
Georgia
Illinois
Maryland
Massachusetts
Michigan
Minnesota
New Jersey
New York
Oregon
Rhode Island
Texas
Virginia
Washington
Wisconsin

DISEASE RESEARCH AND DRUG DISCOVERY

WHAT IS IT? Advanced disease specific research, applying biotechnology related techniques, can lead to discoveries of highly promising biological targets for developing new drug therapies, from traditional chemical drug agents, vaccines and innovative new biological therapies as well.

WHAT DOES IT MEAN FOR MASSACHUSETTS? As a leading center for disease-related research, Massachusetts teaching hospitals and university research institutions offer major opportunities for identifying biological targets and discovering potential drug compounds and innovative biological therapies. At the same time, there is a growing base of pharmaceutical and biotechnology companies for translating these drug discoveries into clinical and commercial use.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Pharmaceutical industry

EXAMPLES OF INDUSTRY LEADERS:

Millennium Pharmaceuticals
Partners HealthCare System
Sepracor, Inc.
Vertex Pharmaceuticals

UNIVERSITY LEADERS:

M.I.T.
Harvard
Northeastern
UMass Amherst
Tufts

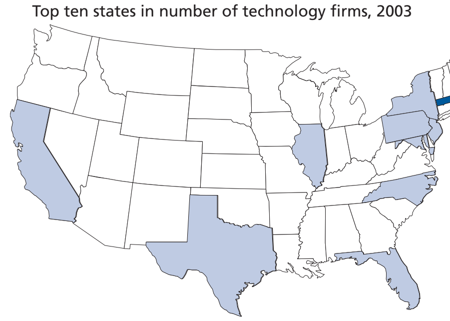
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Pharmaceutical industry	Cluster activities in disease research found in: Cancer research, Cardiovascular research, Infectious diseases, HIV Neurosciences
Biotechnology industry involved in new thera-peutics development	Patent activity in drug discovery and development involving: Tumor suppressors, Neurological drug agents, Anti-infectious drug agents, Drug delivery

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Massachusetts, New York, North Carolina, Pennsylvania, Texas

Technology Industry Presence

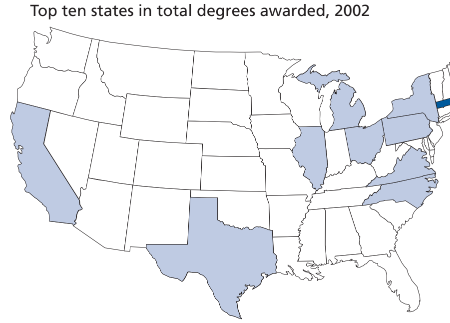
Top ten states in number of technology firms, 2003



1. California
2. New Jersey
3. **Massachusetts**
4. Pennsylvania
5. New York
6. North Carolina
7. Texas
8. Maryland
9. Illinois
10. Florida

Talent Generation

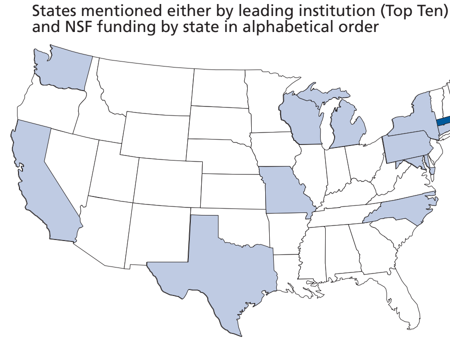
Top ten states in total degrees awarded, 2002



1. California
2. New York
3. Texas
4. Pennsylvania
5. Illinois
6. **Massachusetts**
7. North Carolina
8. Ohio
9. Michigan
10. Virginia

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order



California
Connecticut
Maryland
Massachusetts
Missouri
Michigan
New York
North Carolina
Pennsylvania
Texas
Washington
Wisconsin

BIOMEDICAL DEVICES

WHAT IS IT? Biomedical device technologies involve the convergence of biological processes with materials, electronics and software. The emerging field of biomedical devices is playing into the established and growing health care industry offering major new capabilities from non-invasive techniques to advanced implants and regenerative approaches to new drug delivery approaches.

WHAT DOES IT MEAN FOR MASSACHUSETTS? Massachusetts has a growing base of formal and informal research programs found across university and teaching hospitals that can infuse new technologies into biomedical devices and help position the existing biomedical device industry in Massachusetts for growth.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Biomedical devices

EXAMPLES OF INDUSTRY LEADERS:

ABIOMED
C.R. Bard
Boston Scientific
Codman and Shurtleff, Inc.
Cytyc
Genzyme Corporation
Partners HealthCare System
Phillips Medical Systems
Smith & Nephew

UNIVERSITY LEADERS:

M.I.T.
Boston University
WPI Bioengineering Institute

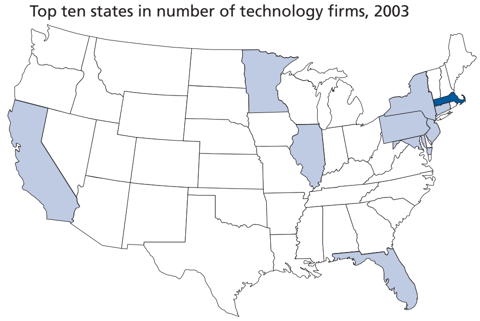
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Biomedical devices	Bioprocessing
	Imaging
	Non-invasive technologies
	Tissue engineering

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

California, Massachusetts, Pennsylvania

Technology Industry Presence

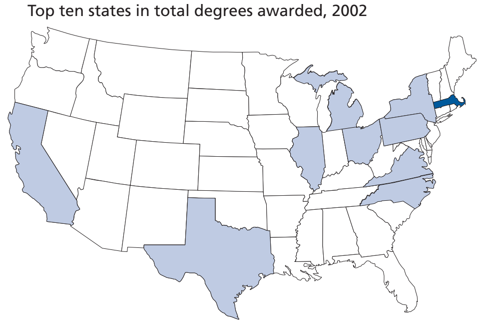
Top ten states in number of technology firms, 2003



1. California
2. Massachusetts
3. New Jersey
4. New York
5. Pennsylvania
6. Minnesota
7. Florida
8. Maryland
9. Illinois
10. Connecticut

Talent Generation

Top ten states in total degrees awarded, 2002



1. California
2. Texas
3. New York
4. Pennsylvania
5. Michigan
6. Illinois
7. Ohio
8. Massachusetts
9. Virginia
10. North Carolina

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order

California
Georgia
Maryland
Massachusetts
Michigan
Missouri
North Carolina
Ohio
Pennsylvania
Texas
Washington

RENEWABLE ENERGY

WHAT IS IT? Renewable energy is involved in developing advanced technologies for harnessing alternative energy generating processes found in chemical reactions, solar power and wind power which do not rely on non-renewable natural resources nor degrade the environment. It draws upon cross-cutting technology areas from polymer research to green chemistry to microbiology.

WHAT DOES IT MEAN FOR MASSACHUSETTS? Renewable energy is an emerging field of technology applications in Massachusetts with a growing base of industry activities and many niche areas of research focus such as biobatteries converting organic waste matter to energy and the use of polymer processing for developing solar power

LEAD PLAYERS

MASSACHUSETTS' LEADERS

KEY INDUSTRY CLUSTERS:

Alternative energy generation

EXAMPLES OF INDUSTRY LEADERS:

Fuel cell-related companies: Ballard, Acumentrics, Nuvera, ElectroChem, ZTEK, Dais-Analytic.

Solar power companies: Evergreen Solar, Konarka Technologies, RWE Schott Solar

Wind power companies: SecondWind, Cape Wind Associates.

UNIVERSITY LEADERS:

M.I.T.

UMass Amherst

UMass Boston

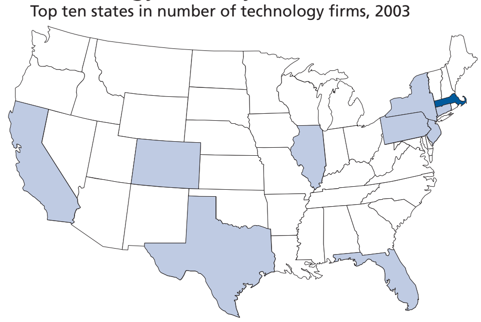
WPI

KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Alternative energy generation companies	Photovoltaic Biobatteries Wind power Fuel cells

LEADING STATES (states ranked highest in all 3 categories researched for the study: Industry Presence, Talent Generation, and Research Excellence)

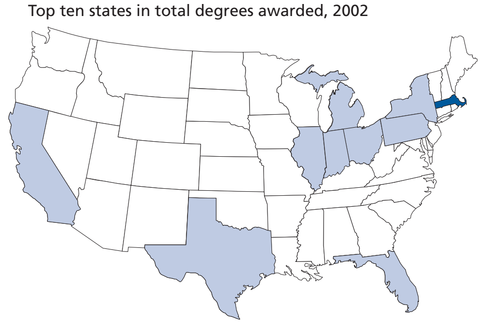
California, Illinois, Massachusetts, New York, Pennsylvania, Texas

Technology Industry Presence
Top ten states in number of technology firms, 2003



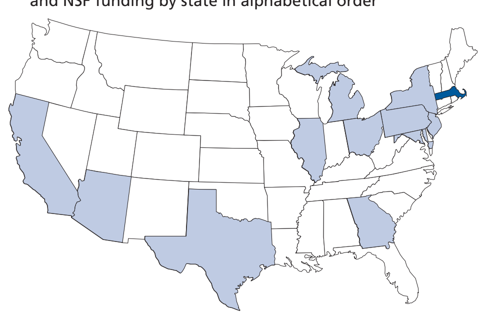
1. Texas
2. California
3. **Massachusetts**
4. New York
5. Pennsylvania
6. Colorado
7. Connecticut
8. New Jersey
9. Florida
10. Illinois

Talent Generation
Top ten states in total degrees awarded, 2002



1. California
2. New York
3. Texas
4. Pennsylvania
5. Michigan
6. Ohio
7. Illinois
8. **Massachusetts**
9. Florida
10. Indiana

Research Excellence
States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order



Arizona
California
Georgia
Illinois
Maryland
Massachusetts
Michigan
New Jersey
New York
Ohio
Pennsylvania
Texas

NANOTECHNOLOGY FABRICATION

WHAT IS IT? Nanotechnology fabrication involves developing new structures based on the precise control of materials architecture at the molecular or atomic level. Nanofabrication has been heralded as a revolutionary advance in manufacturing a next generation of products offering unique properties and decreasing time to market, energy consumption and environmental costs. In particular, nanotechnology addresses the need to scale down the size of chips, the basic building block of our IT-driven economy.

WHAT DOES IT MEAN FOR MASSACHUSETTS? The prospects of nanotechnology to redefine the leading-edge of future manufacturing is real and Massachusetts with its history of precision machining and complex products development has an opportunity to be a leading center for nanofabrication, based on the growing strength of its university research programs. Translating those research competencies in the future into industry competencies will require a focused program of collaboration and strategic alliances.

LEAD PLAYERS

MASSACHUSETTS' LEADERS

UNIVERSITY RESEARCH PROGRAMS:

Many universities in Massachusetts are doing work in nanofabrication—with Harvard, UMass Amherst and M.I.T. among the leading university recipients of nanotechnology research funding—with a particular focus on nanoelectronics, including:

Harvard's Nanoscale Science and Engineering Center in partnership with M.I.T. is a major NSF nanotechnology-funded research center.

UMass Amherst, is advancing the use of polymer templates for nanofabrication to create the pattern of a device's structure, and recently launched the MassNanoTech Center.

M.I.T. has a number of leading nanotechnology research centers including the Nanostructures Laboratory, Soldier Nanotechnologies Center and NanoMechanical Technology Lab.

Northeastern leads an NSF-supported Industry-University Cooperative Research Center focused on contamination and fabrication.

UMass Lowell Institute on Nanoscience and Engineering Technology.

Boston University is focusing on bionanotechnology and has a number of research grants in that area.

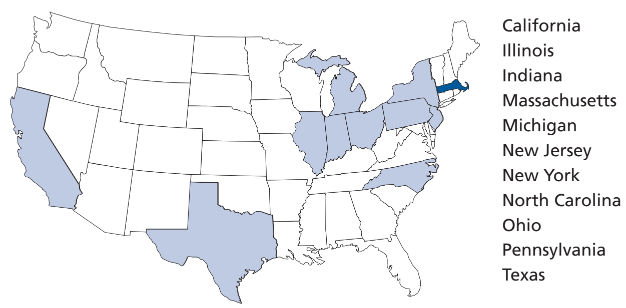
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Advanced materials	Polymer templating for nanofabrication Nanomagnetics
Computer and communications hardware	Nano contamination Nanoelectronics

RESEARCH EXCELLENCE (states receiving highest level of National Nanotechnology Institute awards from the National Science foundation, FY 2001 to FY 2003)

California, Illinois, Indiana, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Texas

Research Excellence

States mentioned either by leading institution (Top Ten) or U.S. News reputation and NSF funding by state in alphabetical order



Note: Nanotechnology fabrication, as a very early stage technology, lacks sufficient data for analysis of industry presence and talent generation.

Advanced materials. The development of materials with unique characteristics and properties, such as strength, wear characteristics, flexibility, and electromagnetic properties. Advanced materials can involve light metals, ceramics, plastics and composites. With advanced properties, a broad range of opportunities are created for higher performing products and waste-free products.

Biogrid. Grids are an emerging networked computing method particularly useful in scientific research areas, such as the biosciences, that are computer intensive, where massive amounts of data are accessed and analyzed. The commonly used analogy is to electrical utilities, where power is switched on only when it is needed. Although a grid system might be complex, involving many machines in many locations, the user is meant to "see" just a single virtual environment, akin to how the Internet works with servers contacting other servers each time a user accesses a Web page.

Bioinformatics. The field of science in which biology, computer science and information technology converge to enable high speed, high-volume analysis and management of biological data, critical to understanding the wealth of data being generated about the presence and role of genes with the advent of biotechnology. Bioinformatics, with its strong roots in computer science, addresses issues of data mining, data visualization, data processing and data management of biological information for use in biological research, drug discovery, diagnostics and treatment.

Biotechnology. Involves the use of cellular and molecular processes to solve problems or make products. At the heart of biotechnology is the ability to manipulate DNA, the molecule that contains the genetic code of all life on earth. Companies involved in biotechnology use the techniques of cellular and molecular biology to develop new therapeutics, diagnostic tools and medical devices.

Bioprocessing. The manufacturing of biological therapeutic products — often discovered through biotechnology — encompassing engineered proteins, vaccines, blood products or gene transfer products. It involves the highly complex, time-consuming and expensive process of growing cells into biological products, often referred to as scale-up manufacturing using bioreactors.

Complex adaptive systems. A system of systems for data and communications that enable real-time, distributed decision-making across a network of systems rather than through point-to-point communications. An example is the need in defense command/control systems to enable different aircraft, ground forces and naval ships to receive mission critical information in real time without the need for intermediaries.

Computer sciences. Involves all aspects of computing from software development to databases to information retrieval and analysis to networking to decision-making and data visualization. Computer sciences stands at the intersection of many converging technologies.

Environmental sciences. The basic physical and biological processes occurring in marine life and oceanography, ecosystems, climate and earth sciences. Its practical applications range from developing new technologies for detecting and monitoring changes in environmental systems to abating or preventing pollution to protecting coastal areas to harnessing the potential of environmental processes for creating new sustainable products.

Genomics and proteomics. The structure and function of genes and proteins. At a fundamental level, genomics and proteomics are akin to information sciences, generating enormous amounts of data that must be organized, analyzed, stored and retrieved. Since most diseases express themselves at the protein-level, knowing how a protein works and is linked with specific genes is crucial to understanding the biological basis of diseases and advancing the development of new drug targets.

Industrial biotechnology. Involves the application of biotechnology to create new types of materials, chemicals, energy sources, and other industry products.

Microelectromechanical systems (MEMS) – MEMS technology is part of the steady trend toward miniaturizing manufactured components. MEMS is an enabling technology allowing the development of smart products that integrate the use of sensors, electronics, mechanical elements and actuators to form small structures at the micrometer scale (one millionth of a meter). MEMS technology is increasingly used in key products, such as cell phones, computers, consumer electronics and biomedical devices. With MEMS technology even traditional products, such as automobiles and industrial machinery, can offer new features and improved performance.

Open innovation. An emerging approach for conducting corporate research & development in which companies seek multiple sources of innovation, including other companies, government and academic labs. It is leading many companies to open research centers next to major research universities and to pursue active outreach through the Internet.

Nanotechnology. The nascent field of nanotechnology involves the manipulation of individual molecules or atoms to create technological useful materials and devices. Thus far nanotechnology has been used to make pants that won't stain, tiles that won't chip and windows that won't get dirty as well as increasing the amount of data that can be stored on a computer by twenty-fold. In the future, it is expected to produce new forms of semiconductors, improved drug delivery and advanced energy systems.

Renewable energy. Application of advanced technologies for harnessing alternative energy generating processes found in chemical reactions, solar power and wind power, which do not rely on non-renewable natural resources nor degrade the environment.

Sensing, optical and electromechanical technologies. A broad set of technologies that enable measuring, sensing, actuation and the fusion of electrical and mechanical systems in ever more miniaturized size, critical to advanced instruments, machinery and components.

Signal processing. Involves a wide range of activities for transmitting, processing and analyzing signals from audio, video, image and radar systems. It is a foundation technology for communications, computing and embedded systems found in devices.

Smart materials. A particular class of advanced materials that interact with the environment to take on specific properties or enable new capabilities, such as sensing or power generation.

Systems biology: An emerging field of that combines biology with mathematics and engineering to create simulations useful for predicting how biological systems function.

Technology convergence. A changing pattern of research in which interdisciplinary research is essential for creating new research fields that are addressing difficult subjects from climate change to biodiversity to disease research.

Technology commercialization. The process of translating research discoveries into viable technology products. This process spans the identification and protection of intellectual property, assessment of market potential, proof of concept research and licensing of technology or formation of new business ventures.

Data Sources Analyzed for *Choosing to Lead: The Massachusetts' Technology Road Map and Strategic Alliances Study*

National Science Foundation Data and Publications:

- Academic Research and Development Expenditures, FY 1985 to 2001
- Research and Development in Industry, FY 1985 to 2000
- Federal R&D Obligations, FY 1985 to 2001

Cluster analysis of:

- 11,000 abstracts of patents issued to Massachusetts companies, January 2000 to June 2003
- 4,000 abstracts of active National Institutes of Health awards to Massachusetts entities as of July 2003
- 2,700 abstracts of National Science Foundation awards to Massachusetts entities, October, 1999 (start of FY 2000) to August, 2003
- 3,500 grants reported in RADIUS database of federal research grants maintained by Rand Institute from other federal agencies, including Department of Defense, Department of Energy, Veterans Administration, Environmental Protection Agency, and NASA, October 1999 to July 2003.

ISI Thomson Scientific University Science Indicators database of publications and citations, 1997 to 2001

Current Federal Agency R&D Strategic Plans and Broad Agency Announcements as of October 2003 for:

- NIH
- NASA
- Department of Energy
- DARPA/Department of Defense
- National Science Foundation
- Department of Homeland Security

Massachusetts Technology Collaborative, R&D Funding Scorecard, 2004

CorpTech Directory of technology companies, June 2003

National Center for Education Statistics database on graduates by field, FY 1996 and FY 2002

Mass Insight/Battelle Interviews, Survey and Focus Group Discussions: Input from over 100 technology executives and 100 university administration and leading faculty

Mass Insight Corporation

18 Tremont Street, Suite 930

Boston, MA 02108

tel: 617-722-4160

fax: 617-722-4151

email: insight@massinsight.com

www.massinsight.com