Choosing to Lead:

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

Strategic University-Industry Alliance Opportunities

The Massachusetts Technology Road Map and Strategic Alliances Study

2004

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Mass Insight Corporation

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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 growth across all regions in Massachusetts.

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.

Meeting the New Terms of Competition

The global competition to be an attractive and effective location for creating new and commercially viable technologies has now entered a new and dramatically different era. In this new era, states and nations confront a new set of competitive imperatives.

Key to success is not just the presence of leading research universities and teaching hospitals, and a sizable base of technology firms—but how they work together. **Strategic alliances and enhanced capabilities to connect research drivers with industry development are the critical ingredients for staying competitive in today's global, knowledge-based economy.**

But Massachusetts has yet to make the conscious determination to adopt this new model. Meanwhile, key competitor states—including California, North Carolina, Pennsylvania and New York, among others—are hard at work mastering the new terms of competition in technology innovation and economic competitiveness. These states are setting new directions for fostering strategic alliances and connections between research drivers and industry development.

To address this situation and put Massachusetts back on track to ensure its leadership in the next generation of technology innovation, a broad consortium of industry, health care, university and economic development organizations came together to develop a technology road map of its core technology strengths to inform investments for the future as well as jump-start new strategic alliances that can give Massachusetts a leg up on its competition.

This part of the report offers Massachusetts a set of specific ideas for strategic university-industry alliance opportunities. The primary purpose of identifying these opportunities is to prompt discussion, analysis and action. **These opportunities point to key areas for investment to enable Massachusetts to be more competitive for federal funding as well as to create stronger synergies between industry and university research and capabilities.** A logical next step would be to convene an interested group of stakeholders from academia, industry and government to review each initiative. The review could recommend whether the initiative should be pursued further, and, if so, develop further detail and an action plan.

The second, more subtle goal of identifying potential strategic opportunities is to institutionalize a process by which Massachusetts can continually remain at the forefront of innovation. A thorough review of these ideas and successful implementation of one or more of them in some form will create a repeatable process, encouraging Massachusetts thought leaders to continue to identify and bring forward such ideas.

Finally, it is important to note that although Massachusetts is already a national leader in some of the areas the initiatives address, Massachusetts has not necessarily successfully marketed that leadership. An important component of follow-up in some of these strategic areas is a coordinated approach to establishing a clear national perception that Massachusetts is the "go-to" state for the research, development and innovation needs of industry and government in a given area.

Key Points on the New Terms of Competition

- University research excellence is no longer the sole province of Massachusetts.
- The demands of success in many important fields have changed.
- The demands of industrial innovation are changing.
- Nine strategic alliance opportunities identified for investment by stakeholders in Massachusetts have been identified.

Changing Terms of Competition

The study's emphasis on strategic alliances follows from recognition of the new competition for industry and talent among regions. This new competition reflects three key developments:

- *First, university research excellence is no longer the sole province of Massachusetts.* Other states as well as players abroad have built top quality research positions in a range of fields.
- *Second, the demands of success in many important fields have changed.* Scientific excellence in fields like the biosciences and advanced materials demand interdisciplinary collaboration and Big Science investments. Achieving the critical mass of capabilities and resources required to support productive R&D in these fields demands the combined efforts of multiple institutions. Even a Harvard or MIT cannot go it alone.
- *Third, the demands of industrial innovation are changing.* Companies are moving away from a reliance on internal R&D and seeking broader sources for innovation across universities, other firms and federal research labs—a phenomenon referred to as "open innovation." With open innovation, the level of collaboration between universities and local industry becomes critical for advancing technology innovation in a specific area.

Research talent and high technology industry will go to those places best able to provide an integrated complex of R&D capabilities.

Together, these developments suggest a new global competition for research talent and high technology industry. Research talent and high technology industry will go to those places best able to provide an integrated complex of R&D capabilities that may readily be drawn upon to meet the changing demands of innovation.

To capture the locational advantages in innovation today, Michael Porter from Harvard University and Scott Stern from MIT explain: "Companies must pro-actively invest to tap into the strengths of their local environment. This involves such things as active participation in industry associations, investing to build deep relationships with local universities, cultivating and assisting programs that train skilled personnel, and paying particular attention to the most sophisticated local customers."[1]

The same is true for state economic development investments—states can and must play an important role in spurring initiatives to foster these new strategic alliances and investing in building capacity and connections between research drivers and industry development. A new dynamic is beginning to emerge.

States are becoming facilitators and investment partners, often "lead" investment partners. They recognize the importance of establishing first-rate public research universities to generate needed pools of talent and to be effective in partnering with industry and complementing private university and teaching hospitals. States today are focusing on filling gaps in the commercialization process of promising technologies in order to reap the benefits of their research base. And states are engaging in regional development efforts, ensuring that all regions have an appropriate technology driver to ensure economic growth.

1 Michael E. Porter and Scott Stern, "Innovation: Location Matters," MIT Sloan Management Review, Summer 2001, page 36.

A technology road map to identify strategic alliance opportunities

A key focus of the Massachusetts Technology Road Map and Strategic Alliances Study is to encourage Massachusetts to think boldly and broadly across its core technology focus areas—which represent a critical mass of skills and know-how—and translate them into strategic alliance opportunities that reach across strengths found in universities, teaching hospitals, federal research centers and industry.

Major strategic alliance opportunities identified in this report suggest major new multi-institutional, multi-disciplinary research centers, often with "go to" signature facilities, typically drawing on federal funding or major industry consortiums. These initiatives all share the goal of enabling 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.

The nine strategic alliance opportunities were developed though a number of considerations:

First, an assessment was made of the 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.

A second consideration was the availability of federal R&D funding in the technology field that 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. State match funding used in support of cross-institutional collaboration can help secure federal support.

Third, the real prospect of linkages to industry active in Massachusetts was a key consideration in developing strategic alliance opportunities. Connections to Massachusetts-based firms offer an important potential pathway to economic development in Massachusetts. State initiatives, including match funding, could encourage the connection to key in-state industry groups. 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.

Fourth, possible opportunities were screened with regard to the size of their likely economic impact generally. The goal was to focus resources on the opportunities with the greatest potential payoff. Assessments involved a mix of public information on private market forecasts and expert interviews.

Technology Road Maps Help Set a Focus and Drive Results in Science and Technology Initiatives

Regions of **New York** state have conducted core technology focus studies to identify new areas for Centers of Excellence.

Pennsylvania in its recent Life Science Greenhouse Initiative required each of its three regions to undertake a strategic plan on how to position the regions in life sciences.

Ohio is focusing investments in technology development around five specific areas of core technology focus in the state.

The **Georgia** Research Alliance developed a framework for life sciences development identifying three key sectors.

Transforming technology strengths into economic advantage through strategic alliances and technology networks

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**. They demonstrate the range of opportunities available to Massachusetts and help inform approaches for realizing these opportunities. 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.

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 clean technologies
9. Ocean exploration and management R&D consortium

These opportunities suggest a **range of options** for Massachusetts, each of which demonstrates important features:

- **Multiple technological strengths.** These opportunities typically draw upon a number of the core technology focus areas found in Massachusetts.
- **Benefit shared by a cross-section of industries in Massachusetts.** These nine opportunities are expected to engage a range of key industries in Massachusetts. No state should become too dependent on any one sector. Massachusetts has the luxury of a diverse industrial economy and should take full advantage of many possible drivers of future growth.
- **Geographic reach to all regions in Massachusetts.** All regions of the state are included in at least one of these major research center opportunities.

The nine major opportunities are presented with respect to each of these dimensions in Table 11.

Complementing the nine major strategic alliance opportunities are five **technology connecting networks,** more focused efforts to translate the potential of research into tangible economic advantage, by linking the capabilities and discoveries generated at research institutions with industry. Beyond advancing Massachusetts' technology leadership in emerging areas through major research centers, Massachusetts must ensure 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."

These technology development networks focus on addressing gaps in the process of translating research activities into commercial products, and generally include applied research, proof-of-concept, product development and prototyping initiatives. Typically, these technology connecting activities require upfront state investments to get the activity established, and then trigger cost sharing or matching funds by industry.

Five specific technology connecting activities are suggested:

- Statewide bioscience therapeutics commercialization entity
- Bioprocessing consortium
- Statewide medical device technology development network
- Statewide network of product development centers to advance high value manufacturing partnerships
- A new "computer grid-based" test bed for information technology and communications technology collaborations

Table 11:

Nine Potential Strategic University-Industry Alliance Opportunities

Many of these strategic alliance opportunities cut across the ten core technology areas where Massachusetts is a national leader.

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 Science Computer Sciences Sensing, Optical, Electro-mechanical Devices	Biotech Fisheries Environmental	Greater Boston Southeast Cape and Islands

CONCEPT PAPER:

Nanoscale Device Fabrication Facilities Network

THE OPPORTUNITY

Catch the next wave of high-technology manufacturing by enabling the development of an integrated R&D infrastructure to support nanoscale device manufacture in Massachusetts.

Massachusetts is a national leader in nanoscale research that promises to transform a wide range of industries, from electronics, to medical devices, bio/pharmaceutical and beyond. Nanoscale research has already spawned a new generation of entrepreneurial companies in the state, but to capture the full economic benefit of early leadership in nanotechnology, Massachusetts must also lead in the engineering of nanoscale devices and the creation of radical new manufacturing practices that will enable fabrication of devices at the nanoscale. By establishing a strong competitive advantage in engineering and fabrication practices, Massachusetts will nurture its early stage nano companies and give itself a competitive edge for capturing a new generation of manufacturing jobs.

Three Massachusetts universities are leading bids on NSF awards supporting major nanotechnology research and fabrication facilities. The success of even one of these bids, as well as an important independent initiative by UMass Amherst, promise a rich array of facilities to support a broad-based position in nanoscale device fabrication. However, 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.

Industries affected
IT, Telecommunications

Regions affected
Greater Boston, Northeast

Total investment required
Low Med **High**

Federal support available
Low Med **High**

Payoff for Massachusetts
Low Med **High**

CONTEXT

Fundamental discoveries in physics and in materials science are driving a nanotechnology revolution that promises to yield computer chips that will extend Moore's Law, drug delivery devices that will pinpoint human disease, and more. Yet the engineering and manufacturing practices necessary to produce these revolutionary devices in high volumes are largely undiscovered or untested. Federal research funding is backing a variety of approaches pursued by leading universities and firms in order to ensure that the U.S. maintains a competitive position in critical industries such as electronics and bio/pharma.

One broad approach is a "hard materials" approach which seeks to fabricate nanoscale features in a top-down fashion similar to that utilized on conventional semiconductor manufacture. A second broad approach is a "soft materials" approach using self-assembling properties of organic materials, such as polymers, in a bottoms-up fashion.

Massachusetts has a unique opportunity to pursue nanoscale systems manufacturing of devices from both a soft and hard materials approach, and on the intersection between these approaches. Thus, Massachusetts will increase its chances of successfully exploiting an approaching technology shift by making the investments necessary to sustain multiple approaches until the path of future commercial development becomes clearer.

ECONOMIC BENEFITS – potential size of relevant markets

Nanofabrication has a broad range of applications. The most apparent and well established markets are electronic devices. The NSF estimates the economic impact to be $300 billion per year for the semiconductor industry and $900 billion per year for global integrated circuits in the next 10–15 years.

Nanotechnology promises to spur developments along at least two trajectories. First, it offers dramatic increases in miniaturization, which will expand the range of device applications such as in the computing, telecommunications, defense and medical device sectors. Second, it offers increased functionality, which can enhance many existing products. For instance, electronics based on nanotechnology could be bent or deformed without affecting performance, thus enabling applications such as wearable electronics and large area electronics.

FEDERAL FUNDING PROSPECTS

Overall funding prospects for nanotechnology research are positive. In December 2003, Congress enacted the Nanotechnology Research and Development Act, authorizing $3.7 billion over the next four years for federal nanotechnology programs. The bill funds the National Nanotechnology Initiative (NNI), which involves nearly 20 agencies, at $849 million, a 9.8 percent increase over FY 2003.

NSF's Nanoscale Science and Engineering Center (NSEC) program provides $1–4 million per year, over 10 years, for engineering research that is increasingly applications-oriented—a critical investment in transforming nano-research into nano-product that will generate new firms and new jobs. NSEC awards also enable universities to accumulate critical equipment and construct clean room and other facilities that can be shared with industry, and thus provide an ongoing infrastructure for the growth of nano industry in the state.

The new National Nanotechnology Infrastructure Network (NNIN) also focuses on facilities. This network of user facilities will supersede the National Nanofabrication Users Network (NNUN).

TIME FRAME

In the near term, Massachusetts should support new research capabilities at its universities to advance innovative manufacturing approaches. High priority should be given to matching new engineering research programs and facilities to the needs of the emerging cohort of Massachusetts "nano companies," many of them direct spinoffs from universities. In the longer term, university-based nanotechnology facilities can be the basis for significant industry collaborations, including proof-of-concept demonstrations, technology transfer and the spin off of new companies.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

Many universities in Massachusetts are working in nanofabrication, with a particular focus on nanoelectronics.

- One leading national center is the Nanoscale Science and Engineering Center led by Harvard in partnership with MIT and several out-of-state institutions. This is a broad-based research effort focusing 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.
- MIT has an historic strength in these areas of electrical fabrication and devices. One area that is drawing particular attention is the Institute for Soldier Nanotechnologies (ISN).
- 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.

- Northeastern, with an NSF-supported Industry-University Cooperative Research Center, focused on contamination and fabrication, leads a team (including UMass Lowell and UNH) in contention for one of NSF's Nanoscale Science and Engineering Centers (NSEC). This team made it to the final round in the last award cycle and is well positioned for this round. Winning this center would place two NSECs in Massachusetts.
- Boston University, together with Boston College and UMass Amherst, is also leading a bid on an NSEC, this one focusing on bionano.

Potential for Industry Linkages

Many companies involved in nanotechnology are start-ups, presenting an opportunity for Massachusetts to host high-growth businesses. In addition, many existing electronics and materials companies based in Massachusetts may be a path to market for innovative nano-technology manufacturing.

While Massachusetts is not home to major fab lines, Massachusetts firms remain leaders in the fields of semiconductor equipment, related instrumentation, "fabless" semiconductor design, and in computer-aided engineering and design tools for the worldwide semiconductor industry. A number of major companies (>$50,000,000 sales) could be interested in this major strategic alliance opportunity.

Illustrative examples of Massachusetts companies that may be interested in advancing nanofabrication technologies include: Analog Devices; Brooks Automation (manufacturing equipment for semiconductor and other clean environment manufacturers); Varian Semiconductor (ion deposition equipment); Allegro Microsystems (IC manufacturing); M/A Com (Tyco subsidiary, RF and microwave semiconductors); Intel (Hudson facility); Sipex (analog ICs); Kopin (wafer-scale devices, flat panel technology); Raytheon; Thermo Electron; PerkinElmer; Waters; Millipore; Teradyne; and MKS Instruments, among others. Additionally, Applied Materials, the largest semiconductor equipment manufacturer, leased 100,000 sq. ft. of space in Danvers several years ago, with plans to open a major facility. The local R&D community was cited as one of the reasons. The economic downturn put those plans on hold, but an industry upturn could open the possibility for a return.

COMPETITIVE POSITIONING OF MASSACHUSETTS

Indicators of Strength

- Massachusetts has breadth to pursue multiple approaches. Strengths include hard materials, soft materials and contamination issues.
  - Massachusetts' position in electronics R&D is underpinned by a broad strength in materials science and engineering as measured by the impact of publications. Research at each of five institutions, MIT, UMass Amherst, Northeastern, Harvard, and UMass Lowell is cited at least 50 percent more than the national average.
  - Massachusetts also has a broad strength in organic chemistry and polymer science led by MIT, UMass Amherst and Harvard, which rank 1st, 5th and 10th in the nation, respectively, in total citations.
- Massachusetts is a leader in new research awards by participating NNI agencies in the 2001–2003 period. Massachusetts institutions also topped the list of competitors for NSF nanoscale research funding—MIT, Harvard, and UMass Amherst ranked one, two and three, respectively, in new nanoscale research awards.

Examples of Leading Initiatives in Other States

New York State was neck and neck with Massachusetts in new NNI nanoscale research awards during the 2001-2003 period. New York already has three national centers of nanoscale research, though just one focuses primarily on electronics applications. However that center, Cornell, is a leader in the National Nanofabrication Users Network—and is far and away the leader in active nanoscale research awards by NSF in this period. Moreover, New York has strong connections to the semiconductor industry through the University of Albany, now part of Sematech North.

Other possible benchmarks for the proposed investment in nanoscale fabrication facilities in Massachusetts are provided by a number of facilities currently participating in the NSF's National Nanofabrication Users Network. In addition to Cornell, these include nanofabrication facilities at Penn State, Stanford, and UC Santa Barbara. These sites have been designated by NSF as national centers for nanofabrication.

New Jersey is an example of another up and coming state. New Jersey aspires to develop a similar scale facility at Princeton—the Princeton Institute for the Science and Technology of Materials (PRISM). Princeton is a finalist in contention for inclusion in NSF's National Nanofabrication Users Network. If a proposed bond issue passes in 2004, New Jersey will largely fund the space, building, and provide long-term facilities support.

SPECIFIC ACTIVITIES AND STATE SUPPORT REQUIRED

The broad goal should be to establish a working alliance for nano-device engineering and fabrication that will guarantee Massachusetts nanoresearchers and entrepreneurs access to critical test, measurement, characterization and prototype fabrication facilities, as well as promote engineering research collaborations. This alliance should be part of the overall Massachusetts Nanotechnology Initiative or a successor organization.

A number of specific proposed activities deserve careful consideration for near-term support:

1) Several Massachusetts institutions have created long-term strategies to build up their programs in nanoscale engineering and fabrication. These institutions include UMass Lowell, UMass Amherst, Harvard, Northeastern University, Boston University (BU) and MIT. The thrust of research at these institutions is broad and could provide an unparalleled set of complementary capabilities for the growth of nanotechnology firms in Massachusetts.

2) Massachusetts needs to provide specific support for institutions competing in the NSF's highly competitive program for the creation of Nano Science and Engineering Centers (NSECs). A proposal is currently pending from Northeastern University and UMass Lowell, and others are likely during the next two years.

Research and fabrication facilities that enable experimentation with nanoscale devices are inherently expensive; investments as high as $5–$10 million may be required as a state match for cost share of some NSF centers. Facilities are also subject to rapid obsolescence due to the fast pace of technology turnover in the field. Nevertheless, states that create an effective network of such facilities for their emerging nano firms will greatly enhance their prospects for growth.

The unparalleled breadth of nanoscale research underway in Massachusetts means that the state need not place all its bets on a single type of nano-device or a single industry. The state has a window of opportunity to promote radical innovation in manufacturing practices serving a wide range of nano firms. These firms will then serve an equally wide range of end users in the electronics, bio/pharma, medical device and other industries. A "smart growth" strategy for Massachusetts will be one that aggressively supports a network of university-based facilities with access for new and emerging firms, while facilitating knowledge-sharing on engineering and manufacturing with industry in general.

CONCEPT PAPER:

Smart Materials Technology Incubator

THE OPPORTUNITY

Convert the mission-driven materials R&D of the Soldier Systems Center at Natick Laboratories into commercial technology businesses in Massachusetts.

Massachusetts could position itself to be a leader in "smart materials," a field that encompasses applications including on-body sensors, improved textiles, and lightweight power supply sources. This opportunity can be built around the presence of the unique facilities and R&D efforts of the U.S Army Soldier Systems Center (SSC) at Natick Laboratories as well as SSC's network of relationships with industry and universities, most notably the MIT Institute for Soldier Nanotechnologies.

CONTEXT

SSC at Natick Laboratories is a unique resource in advanced materials and related nanotechnology R&D in Massachusetts. SSC focuses broadly on technology systems supporting the soldier in the field, including the development of protective and monitoring systems embedded in soldier uniforms and integrated power systems.

At the same time, much of what is needed to support soldiers in the field is also of importance to first responders. This insight is helping to advance the National Protection Center (NPC), a joint agency pilot program at Natick Labs that provides state-of-the-art protective equipment to military personnel and civilian emergency responders.

ECONOMIC BENEFITS – potential size of relevant markets

At least two areas of R&D focus at SSC suggest important commercial opportunities:

- *Lightweight, robust power supply systems, including solar power and batteries.* These advances promise to enable the application of solar cell technology to the broadest possible range of markets. In 2002, the global market for solar cells grew by 35 percent. The successful commercialization of low-cost, flexible substrate technology promises a wide open market. The market for small batteries and fuel cells is expected to grow at an annual average rate of 5.7 percent between 2001 and 2006, from $980 million to $1.3 billion. The market for small and portable fuel cells alone is expected to grow to $5–$10 billion by 2020.
- *Smart materials for protective clothing and remote monitoring of the wearer's physical status.* The cross over to non-military and commercial applications of SSC R&D in this area is suggested by the apparent convergence of protective systems for soldiers and first responders. The demands of Homeland Security for equipping first responders suggest a growth market, while improved, lighter weight, smart uniforms would drive a broad market among police forces and firefighters in general.

Industries affected

Medical Devices, Advanced Manufacturing

Regions affected

Greater Boston, Northeast, Southeast, Western

Total investment required

Low Med High

Federal support available

Low **Med** High

Payoff for Massachusetts

Low **Med** High

FEDERAL FUNDING PROSPECTS

The Department of the Army Research Labs, of which Natick Labs is a part, is the most likely source of funding. Other branches of the Department of Defense might also be contributing sources. Another possible funding source is the Department of Homeland Security to equip first responders.

TIME FRAME

This is a near-term opportunity that builds upon a key existing federal research laboratory and relationships with universities and their industry partners.

In the long term, the alliances and facilities built around SSC can be the basis for significant industry collaborations, technology transfer and spin off of new companies.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

Massachusetts enjoys a broad strength in university research in advanced materials, which is complemented by the unique facilities and considerable in-house expertise at SSC.

- University research strengths:
  - Broad strength in materials science and engineering as measured by the impact of publications, with research at each of four institutions, UMass Amherst, Northeastern, Harvard, UMass Lowell and MIT, being cited at least 50 percent more than the national average.
  - Massachusetts also has a broad strength in organic chemistry and polymer science—MIT, UMass Amherst and Harvard rank 1st, 5th and 10th in the nation respectively in total citations.
- SSC strengths:
  - A rich array of research facilities, many unique in the world, such as environmental chambers approved for testing with humans.
  - Deep and extensive in-house expertise in materials R&D that informs its work with universities and contractors.

Potential Industry Linkages

SSC is actively engaged with industry in Massachusetts. Currently, SSC has 14 Cooperative Research & Development Agreements (CRADAs) with Massachusetts companies. These agreements allow for the government to receive additional resources for R&D efforts, keep government and industry on the cutting edge of S&T by allowing renowned scientists to work together, thereby achieving military objectives faster and at a lower cost to DoD. Industry, working under a CRADA, gains the knowledge of SSC's mission and programs and this puts industry in a better position for future contracting potential.

A highly visible and important collaboration for Massachusetts is the SSC's work with Konarka, a Massachusetts-based company, which is working to commercialize a promising solar energy technology developed at UMass Lowell with support from the SSC.

COMPETITIVE POSITIONING OF MASSACHUSETTS

SSC is actively engaged in developing a range of collaborations with universities and firms in Massachusetts. Most visible is the large award to MIT for the Institute for Soldier Nanotechnology. However, SSC is developing a range of university relationships to promote a robust scientific and technical community in Massachusetts.

SSC has signed a Memorandum of Understanding with the University of Massachusetts system, thus enabling a range of R&D relationships with all of the campuses. To date, extensive work with UMass Lowell has led to breakthroughs in advanced nano-based photovoltaic technology.

Examples of Leading Initiatives in Other States

The level of DoD engagement in university-based materials research with the ISN, which is which is managed by the ARO, is unique. However, it is not unique in its strong focus on materials.

The Army has another major research facility with a strong focus on materials science and technology in Dover, NJ—Picatinny Arsenal. Picatinny is the site of ARDEC (Armament Research, Development and Engineering Center). ARDEC falls under the major command of AMC (Army Materiel Command) and TACOM (Tank Automotive and Armaments Command). ARDEC's mission is to conduct or manage research, development and engineering for all assigned weapon systems. Currently, its primary mission is research, development, and pilot-plant production of explosives and propellants for the Army.

Commercialization of technologies developed in connection with Picatinny Arsenal research is supported by the Picatinny Commercialization Center. The Center is an business incubator that provides a range of business services. For technical assistance in compatibility testing or in the design and fabrication of prototypes, tenants in the Innovation Center can access the resources of Picatinny through a simplified Cooperative Research & Development Agreement (CRADA).

SPECIFIC ACTIVITIES AND STATE SUPPORT REQUIRED

Massachusetts must bring together a unique multi-university partnership able to leverage the unique facilities at Natick Labs in a manner that truly allows Massachusetts to demonstrate a broad-based R&D capacity beyond the capabilities of any one university.

SSC boasts a rich array of research facilities, many unique in the world, such as environmental chambers approved for testing with humans. Not only is SSC a source of support for external R&D, but a key resource for allowing a range of R&D to be undertaken by universities and industry in Massachusetts.

These relationships by themselves will not necessarily lead to commercial developments in Massachusetts. Though often crucially important to SSC's mission, enabling commercial opportunities is not a primary goal of SSC. 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 which are outside the scope of SSC's mission.

The state can support the creation of a business incubator linked to 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. The SSC could offer technical assistance in compatibility testing, or in the design and fabrication of prototypes. Tenants in the incubator could access the resources of the SSC through Cooperative Research & Development Agreements (CRADA).

CONCEPT PAPER:

Neuroscience Systems Biology Consortium

THE OPPORTUNITY

Marshall the growing neurosciences R&D complex in Massachusetts to enable cutting-edge approaches to drug/therapeutic discoveries.

Massachusetts could become a leading center for neuroscience systems biology, focusing on signal pathways research in the brain, which can be a key to advanced development of innovative therapeutics and interventions for hard to treat neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease, as well as mental and neuro-muscular diseases.

CONTEXT

Similar to other areas of drug discovery, key innovations are expected from convergence of fields such as genomics/proteomics, pharmacology and combinatorial chemistry to identify specific pathways associated with major neurological and psychiatric disorders and help target new drug development. However, given the complexity of the brain, it is likely that the most promising therapeutic strategies will involve a combination of systems understandings of brain function as well as traditional drug development strategies.

ECONOMIC BENEFITS – potential size of relevant markets

The global neuroscience pharmaceutical market is estimated at $60 billion, second only to cardiovascular therapeutics. It is a market very open to improved, innovative therapies. Most current treatments focus on managing symptoms, not reversing disease, and have significant side effects associated with their use. Many neurological disorders are closely associated with older populations, thus the aging of baby boomers, plus longer life span will increase their incidence and the importance of new therapies.

FEDERAL FUNDING PROSPECTS

This area of research falls within one focus area in the National Institutes of Health (NIH) Road Map (Biological Pathways and Networks) and a major NSF initiative (Integrative Biology and Neuroscience).

The November 3, 2003 issue of *The Scientist* estimates funding for neurosciences research at $4.8 billion from NIH for 2004, $103 million from the NSF-Integrative Biology and Neuroscience and $450 million from venture capital investors in 2003. In addition, private foundations/gifts (examples: The Picower Foundation, the McGovern family) and industry collaborations (examples: Merck, Pfizer, Genzyme) are major potential sources.

Industries affected

Biotech, Medical Devices

Regions affected

Greater Boston, Central, Western

Total investment required

Low **Med** High

Federal support available

Low Med **High**

Payoff for Massachusetts

Low **Med** High

TIME FRAME

This neuroscience consortium can be achieved in the near term given the opportunity of funding through the NIH Roadmap Initiative.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

For Massachusetts, neuroscience represents a major area of new investment across a broad range of institutions. Some investments are focused on molecular mechanisms while others bring a cognitive systems approach. It is expected that future therapies for neurodegenerative and neuromuscular diseases will require an integration of these approaches given the complexity of the mind.

There are a number of Massachusetts institutions now pursuing the type of interdisciplinary research that is needed to provide cutting-edge advances in neuroscience.

- MIT has several focus areas, including the McGovern Institute for Brain Research, focusing on how the brain works from the level of gene expression in individual neurons to the interrelationships between complex neural networks; the Picower Center for Learning and Memory; and the Department of Brain and Cognitive Science that combines molecular and cellular neuroscience, systems neuroscience, computational neuroscience, and cognitive neuroscience.
- Harvard Medical School is a major national player in neurosciences with its Center for Neurodegeneration and Repair. This center includes groups involved in translational neurological research, imaging, bioinformatics, and molecular research. The Laboratory for Drug Discovery in Neurodegeneration (LDDN) provides assistance to investigators with assay design, high throughput screening, medicinal chemistry, and biostatistics.
- Partners HealthCare System supports a number of major efforts including the Mailman Research Center (McLean Hospital), the Neuroimaging Center (McLean), Massachusetts General Hospital (Alzeiheimer's and other neurodegenerative diseases).
- Tufts University is investing in expanding its interdisciplinary neuroscience program that combines neurobiological and neurogenetic investigations.
- Boston University brings a focus on cognitive and neural systems, mathematical and computational neuroscience, and supports the Center for Memory and Brain.
- Brandeis, through the Benjamin and Mae Volen National Center for Complex Systems, houses an interdisciplinary program in neuroscience.
- UMass Worcester has focused on neurobiology as a primary strategic area for research activity.
- UMass Amherst brings significant basic research strengths in neurobiology and neurosciences, particularly involving neural development, brain differentiation and function and neural cell death, as well as neuroendocrine processes. UMass Amherst is undertaking a range of cognitive sciences research with large grants from industry (Microsoft) and federal sources—military and civilian.

Potential for Industry Linkages

Advances in neuroscience research represent a potential area of future development although it is not a major emphasis of life science companies in Massachusetts today. In terms of small companies, Massachusetts' most significant competitor is California. Most major large pharmaceutical companies have significant programs in pharmaceutical treatments including (but not limited to): Merck, Pfizer, Novartis, Amgen, Wyeth, and Astra Zeneca. California has a number of small biotechnology companies which have attracted pharmaceutical dollars to the West Coast. Based on the critical mass of investigators and technologies, Massachusetts has the opportunity to compete with California and other states for small and large company interest. Medical device companies such as Medtronic also represent potential industry partners.

COMPETITIVE POSITIONING OF MASSACHUSETTS

Indicators of Strength

Massachusetts ranks highly overall and broadly across institutions in neuroscience-related fields as viewed by publications analysis.

- Statewide, Massachusetts is a leader in academic publications in neurology and neurosciences, reflecting both depth and excellence. From 1997 to 2001, Massachusetts universities comprised 7.8 percent of all publications in neurology (76 percent higher than average level of citation per publication), and 8.7 percent of all publications in neurosciences (87% higher than average rate of citations per publication).
- Four institutions in Massachusetts have a 50 percent higher citation rate than the nation in neurology (UMass Amherst, UMass Worcester, Harvard and BU).
- Five institutions have a 50 percent higher citation rate than the nation in neurosciences (UMass Amherst, UMass Worcester, Brandeis, Harvard and MIT).

Development of many neurological therapies is still a long term plan but there are indications in which the pay off is likely to occur much sooner if industry and academia can combine forces and focus on promising leads. Massachusetts possesses a significant competitive advance in the geographic proximity of industry (biotech and pharma) to basic and clinical research groups. The state also has an advantage in the commitment of its academic community to become the "center of the universe" in the field of neuroscience.

Examples of Leading Initiatives in Other States

It is only recently that organizations in Massachusetts have begun to formalize large interdisciplinary research groups in the field of neuroscience. In this respect, Massachusetts trails other parts of the country. A number of universities in other states have been more aggressive in this field, including:

- Washington University in St. Louis
- University of Florida
- Johns Hopkins
- University of Pittsburgh

Washington University, St. Louis, Missouri. Washington University has 145 faculty participating in neuroscience research with three research centers and one institute: The Center for the Study of Nervous System Injury, the Alzheimer's Research Center, the Imaging Research Center and The Neurosciences Institute. Key research themes include: neurodegenerative diseases, signal transduction, cognitive neuroscience, regeneration and repair, imaging, and neural development.

University of Pittsburgh, Pittsburgh, Pennsylvania. The University of Pittsburgh has a number of groups involved in neuroscience research including the Neurobiology Department, The Neurobiology Interdisciplinary program (located in the Medical School), the Department of Neurology, The Department of Neuroscience, and The Department of Neurosurgery. The major collaborative program is the Neurobiology Interdisciplinary program which has approximately 70 faculty involved in six major themes: The molecular basis of cellular communication; psychiatric and neurological disorders; information processing in brain circuits; neural development and cellular growth; cognitive neuroscience; homeostatic regulatory systems. The University of Pittsburgh also is partnered with Carnegie Mellon University in an NSF-funded Center for Neural Basis of Cognition.

The University of Florida. One of most comprehensive centers for neuroscience research can be found at the McKnight Brain Institute at the University of Florida. The Institute is located in Gainesville and is represented by over 300 faculty from 51 academic departments and ten colleges, encompassing programs in basic, clinical and translational neuroscience. Collaborators include scientists from other parts of the world. A $60 million building serves as a focal point for the multi-disciplinary research programs. The programmatic matrix for the McKnight Brain Institute includes: virology and neural genetics/gene delivery/knockout technology; developmental neuro-biology, neuro-cancer and neuro stem cell biology; brain and spinal cord traumatic injury, stroke and epilepsy; sensory systems, pain and movement control/disorders; neurorehabilitation (cognitive and motor/sensory); learning and memory (including motor/sensory experiential remodeling); neuro-biology of aging (Alzheimer's disease); cognitive neuro-science and mental illness; neural control and responses to immune, endocrine and other homeostatic systems; neuro-toxicology, substance abuse and addiction; brain-machine interface (neuro-robotics, prosthetics and enhancements) and bionano sensors/motors; computational and network neuro-science; structural neurobiology and functional neuro-imaging.

Johns Hopkins University. Johns Hopkins University has three centers and one institute devoted to neuroscience research: the Alzheimer's Disease Research Center, The Center for Inherited Neurovascular Diseases, the Parkinson's Disease Research Center of Excellence, and the Mind-Brain Institute. The Department of Neuroscience has 20 primary appointment faculty and 48 faculty with appointments in other departments. Utilizing a number of technologies (including genetics, molecular biology and biomedical engineering), Johns Hopkins faculty perform basic and clinical research in behavioral and cognitive neuroscience, signal transduction, movement disorders, and neurodegenerative diseases.

SPECIFIC ACTIVITIES AND STATE SUPPORT

Consider a multi-institutional center for neuroscience signal pathways taking advantage of imaging, visualization and software capabilities across Massachusetts institutions. Facilitate technology transfer by linking and expanding drug development initiatives currently in place (e.g., the Laboratory for Drug Discovery in Neurodegeneration at Harvard Medical School).

State support will be required to match possible federal NIH funding.

CONCEPT PAPER:

Biogrid

THE OPPORTUNITY

Build a specialized regional IT infrastructure to create a unique R&D environment in Massachusetts to attract and grow the biomedical industry.

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 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 pharmaceuticals R&D.

Industries affected
IT, Telecom, Biotech, Pharmaceuticals, Health Care

Regions affected
Greater Boston, Central, Western

Total investment required
Low Med **High**

Federal support available
Low **Med** High

Payoff for Massachusetts
Low Med **High**

CONTEXT

The major challenge to the pharmaceutical industry and one of the key drivers of the biotech industry is the need to improve the productivity and output of the research pipeline for therapeutic drugs. Pharmaceutical companies can utilize the biogrid to selectively collaborate with biotech partners, researchers at universities, clinical specialists and researchers at medical centers and hospitals and, potentially, with regulatory authorities. The data management and security required to enable this collaboration will attract information technology firms to the biogrid effort.

The biogrid will be built around facilities physically shared (owned or managed by a service provider) and/or virtually shared (owned and managed by the institutions participating in the grid). This architecture allows the cost to be spread over multiple organizations. It permits greater utilization of expensive facilities as well as the provision of services to smaller entities who could not otherwise afford the resources. The biogrid would thus be a significant attraction to start-up and early stage firms, allowing them to pay for what they use rather than consume scarce capital resources building their own infrastructure.

The biogrid would provide a shared, secure environment for computing, heterogeneous data management, simulation and visualization. It would facilitate the creation of new collaborations around the emerging area of systems biology where previously unconnected researchers are reaching across related disciplines to build a new construct in biology.

Systems biology is an integrative discipline aimed at bringing together the knowledge gained at different levels of biology—e.g. molecular biology, genetics, proteomics, cell biology, organ systems—at a higher level to model and understand living systems. Each of these disciplines has its own data modalities and structures, so a significant component of systems biology is knowledge creation and management from this disparate data. This effort will proceed through the creation of "in silico" models of various levels of biological systems, driving a demand for computation, simulation, visualization and extensive data management capability. It is the need to build these complex models that has attracted physicists, computer scientists, mathematicians and engineers to this new discipline.

The ability to build knowledge collaboratively benefits all levels of the life sciences enterprise. As Eric Lander of the Broad Institute observed of the Human Genome Project, it is as if Massachusetts has been provided the parts list of a Boeing 777, but does not yet have the knowledge to put them together. Systems biology aims to create that knowledge.

The biogrid would also advance IT, grid computing, communications, data management and data security infrastructures by developing a grid model that goes beyond distributed computer farms, vaulting Massachusetts into a leading position in this emerging area.

Finally, the biogrid would enhance the market for talent and the attractiveness of Massachusetts by creating a "virtual workplace" where universities, teaching hospitals and industry tap in to share expertise, to learn and to discover new talent.

ECONOMIC BENEFITS – potential size of relevant markets

The collaboration enabled by a biogrid offers to make R&D substantially more efficient, greatly reducing drug and development research costs. This not only saves money for pharmaceutical firms and increases the productivity of drug discovery, but also opens up the industry to new entrants. It allows pharmaceutical firms a more cost-effective way to access knowledge and skills in areas they do not have in-house. The ability to access a shared resource as needed could force down capital costs faced by startups and early stage biotech firms, driving more small enterprise growth in the industry and in Massachusetts.

Providing the data management and security necessary to allow firms and institutions to selectively collaborate and share data on interconnected systems is a major challenge for the information technology industry. Solving these problems opens up significant market opportunities, not only throughout life sciences and health care, where HIPAA requirements are driving IT investments, but in the broader market as enterprises in multiple industries increasingly share information to maximize the efficiency of their supply chain.

The biogrid will use high-speed communications bandwidth, increasing utilization on existing fiber connections like the NoX Metro Ring as well as driving demand for links connecting other locations in Massachusetts. Availability and utilization of a wider array of communications facilities will facilitate the siting of firms in other locations in the Commonwealth.

FEDERAL FUNDING PROSPECTS

- NIH Roadmap Centers Programs
  - National Centers of Biomedical Computing. These centers are intended to create a national software engineering system in which biologists, chemists, physicists and computer scientists anywhere in the country will be able to tap into a supercomputing network to share and analyze data, using a common set of software tools.
  - National technology centers for biological networks and pathways.
- NSF Information Technology Research program.
- DOE high performance scientific computing, genomes for life, and molecular medicine programs.

TIME FRAME

The biogrid infrastructure can go forward in the near term responding to the NIH Roadmap initiative.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

Leading centers of research include the Broad Institute and Whitehead Institute, MIT's Computational and Systems Biology Initiative, Harvard Medical School's new Systems Biology Department, the Martinos Center for Biomedical Imaging at Mass General Hospital, research groups at Harvard DEAS, Boston University, WPI, UMass Worcester, UMass Amherst/Baystate Medical and throughout the teaching hospitals.

IBM, MIT's CSBi and Harvard's DEAS are among the organizations that have taken initial steps toward creation of such a biogrid.

Potential for Industry Linkages

There is a critical mass of companies engaged in genomics and proteomics—biotech firms, IT suppliers, bio IT companies, software firms, communications industry suppliers and providers-and a growing presence of pharmaceutical in Boston. There is an extensive network of university and teaching hospital research groups already collaborating with pharmaceutical and biotech firms locally. The biogrid infrastructure would more effectively link extensive university resources and industry in key fields.

COMPETITIVE POSITIONING OF MASSACHUSETTS

Indicators of Strength

Massachusetts ranks highly overall and has broad positions in the fields underpinning genomics/proteomics and drug discovery:

- Molecular biology and genetics – Massachusetts institutions produced almost 10 percent of U.S. publications. Moreover, each of five Massachusetts institutions have citation rates at least 50 percent greater than the national average.
- Pharmacology and toxicology – four institutions (BU, Tufts, MIT and Harvard) have citation rates at least 50 percent greater than the national average; Harvard ranks #2 nationally in total citations.
- MIT, BU, UMass Amherst ranked #1, #13, and #18 respectively in IT and Communication Systems (total publications).

Examples of Leading Initiatives in Other States

Grid computing is a growing market, with many locations in Europe taking leadership roles. Biosciences users are sought-after users of grid computing. North Carolina established a biogrid project in 2002, with its early efforts focused on using the existing communications infrastructure to provide a shared computing resource, but the effort is still at an early stage. The recent hiring of Dan Reed from the National Center for Supercomputing Applications in Illinois should accelerate their efforts. Michigan is looking at computational needs as part of its Life Sciences Corridor effort. California is well-positioned in locations like San Diego, where there is a national supercomputing center as well as a thriving life sciences industry. However, California's severe budget crisis may inhibit any efforts involving the UC system.

Massachusetts and New England will also be placed at a disadvantage by the development of the new $100 million optical network called National LambdaRail offered by an academic consortium reaching from Atlanta, Chicago, Denver, Jacksonville, Pittsburgh, Raleigh, Seattle, Sunnyvale CA and Washington, D.C. This consortium, which does not include New England, is developing an infrastructure for experimental research on optical networks and other types of advanced scientific, engineering and medical research.

SPECIFIC ACTIVITIES AND STATE SUPPORT REQUIRED

Massachusetts must establish a specialized biogrid development platform as part of the proposed Northeast Education and Research Network, focusing on visualization and simulation tools, connection of microarray and spectroscopy instrumentation, as well as data management and security processes and systems.

As part of the NIH Road Map, Massachusetts should pursue funding for a multi-institutional, multi-disciplinary National Center for Biomedical Computing, focusing on next generation computing, visualization and software applications to gain value of large scale, heterogeneous genomics and proteomics databases. At this point, institutions in other regions are responding to this initial solicitation; it is not clear whether Massachusetts institutions will do so.

Total investment across collaborating organizations is estimated at $3–$5 million in the first year and $10 million in the second year to establish an effective infrastructure and to support development efforts needed to effectively utilize the resources available. Ongoing support in year three and beyond can only be roughly estimated at $3–$5 million per year. Additional funding will be required in selected years to upgrade infrastructure as utilization increases and technology advances. These investments can be shared across participants in the biogrid project.

CONCEPT PAPER:

Next Generation Sensing and Sensor Networks

THE OPPORTUNITY

Massachusetts can establish unique test bed and signature research facilities that can leverage its existing base of research to position itself as a leading center for sensor networks.

A "sensor revolution" is taking shape building on innovative detection and tracking technologies linked through wireless networks. It promises to change the way we protect and defend our nation, manage inventory, maintain sophisticated equipment and track weather, among many other applications. Massachusetts can capitalize on this emerging technology market by drawing together its vast, yet poorly coordinated cluster of capabilities in sensing and imaging spread across federal facilities, universities, teaching hospitals and industry, both to advance integration of sensing technologies and to remain at the leading edge of new technology development.

Industries affected
IT, Telecommunications, Biotechnology, Medical Devices, Advanced Manufacturing

Regions affected
Greater Boston, Northeast, Central, Western

Total investment required
Low Med **High**

Federal support available
Low Med **High**

Payoff for Massachusetts
Low Med **High**

CONTEXT

Imaging and sensing technologies are key enablers for a broad range of applications in defense, medical, environmental, transportation and other sectors. Historically, sensors and signal processing have been a core competency of defense-related industries. From the use of radar in World War II, pioneered in Massachusetts, through tracking systems for ballistic missiles during the Cold War to today's information-based warfare, signal processing has expanded from one or two sets of frequencies within the electromagnetic spectrum to a wide range of frequencies and modalities, each requiring its own development of sensors, signal processing and information and visualization technologies.

These same techniques have found their way from military to civilian application in areas including medical diagnostics and therapy, air traffic control, weather tracking and forecasting, geospatial observation, environmental monitoring and others.

The key challenges going forward include developing networks of different sensors across multiple sites and integrating multi-modal data from a variety of sensor types in multiple locations. The vastly increasing data flow from a range of sensing devices also demands new models for processing, storage, retrieval and management of the data generated. Advances in knowledge management and visualization tools will enable the integration of that data into information and knowledge that can be acted on—by people as well as by new classes of devices and systems.

ECONOMIC BENEFITS – size of potential markets

- Major market in industrial sensors. The market for sensors overall is predicted to grow at an average annual rate of 6.2 percent between 2001 and 2006, from $5 billion to $6.8 billion. The market for sensors integrated into MEMS packages will experience the fastest rate of growth, at an average annual rate of 9.5 percent, reaching $2.1 billion by 2006.

- Major demand from defense and homeland security needs for advanced sensor and detection technologies.
- Medical imaging continues to be a fast growing market, with diagnostic imaging standing at over $10 billion. Increasingly, focused, specific imaging and diagnostic techniques are being developed for specific medical conditions, and are key in development of minimally invasive techniques for providing medical care. A key value for medical applications is the development of networked sensor systems for improving decision-making and remote monitoring.

FEDERAL FUNDING PROSPECTS

Multiple potential funding sources to support a major focus on imaging and sensing in Massachusetts:

- NSF funding available through cross-cutting engineering research program—sensors and sensor networks.
- DARPA strategic thrust area in counter-terrorism involving biological sensors as well as elusive surface targets involving detect, track and destroy functions with sensors.
- Newly formed NIH Institute for Biomedical Imaging and Bioengineering.
- NIH Road Map focus on nanomedicine also suggests a future source of support (center's program launch planned for 2005).

TIME FRAME

Developing a Massachusetts sensing consortium to inventory and connect the breadth of sensing expertise in the state can be an initial, low-cost first step.

Near term opportunities to develop multi-institutional collaborations to pursue federal funding for major new sensing technologies.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

There is a broad range of activities found in Massachusetts, including:

- Lincoln Labs' focus on sensing and imaging of real-time data include missile defense measures and counter measures; air defense including sensor integration and target identification; space control—observing either space or the earth from satellites and tactical technology; and surface surveillance—sensor fusion and 3D visualization for battlefield intelligence integration. An emerging area is rapid biological sensing of pathogens.
- Several labs at Massachusetts General Hospital, including the MGH/MIT/HMS Martinos Center for Biomedical Imaging, focus on high speed and high field magnetic resonance (MR) imaging, MR spectroscopy, optical imaging, magnetoencephalography (MEG), and electroencephalography (EEG); the Center for Functional Neuroimaging Technologies (CFNT) focuses on multimodal MR-based neuroimaging techniques and technologies; and the Center for Molecular Imaging Research (CMIR) at MGH and Harvard Medical School is advancing novel technologies for in vivo sensing and imaging of molecular events.
- The Center for Subsurface Imaging and Sensing (CenSSIS) is an NSF Engineering Research Center headquartered at Northeastern University and includes Boston University, with a particular focus on technology for detecting and imaging hidden objects. Three main thrust areas are non-invasive breast cancer detection, underground pollution assessment and mine detection.
- Worcester Polytechnic Institute's Bioengineering Institute and its Department of Biomedical Engineering work in several sensor-based imaging areas, including untethered medicine, biosensors and neural imaging. WPI has an

active collaboration with the UMass Medical Center advancing MRI analysis for animal brain imaging, including examining drug interactions.

- Brandeis University, which hosts an NIH sponsored regional NMR facility and is bringing on-line one of the most powerful electronic microscopes in the U.S. with technology development activities through its Biophysics and Structural Biology department.
- The Institute for Scientific Research at Boston College focuses on data aggregation, spatial analysis and display of large datasets especially from atmospheric research and environmental studies. Customers include NASA and the Air Force.
- Significant activities across the UMass system in sensors and detection, including: UMass Amherst, developing smart sensors through its chemical engineering and biochemistry departments and a national leader in millimeter and microwave technologies through its electrical engineering department; UMass Lowell, with a group of researchers involved in sub-millimeter wave technologies associated with detection; and UMass Dartmouth, involved in biological sensing and detection of botulinum.

Potential for Industry Linkages

This initiative would allow Massachusetts to better bring together its sensing and imaging capabilities to address defense and homeland security needs relating to range, sensitivity, power consumption, size and mobility through a test bed facility. This facility might also have applications to medical device companies.

Using of sensing and imaging is a major component of the instruments, controls, sensing and mechatronics cluster found in Massachusetts. These sensors and imaging technologies are embedded in key market applications from medical devices such as endoscopy and imaging systems, to industrial systems. Industry groups like MassMedic or a consortium of the research and teaching hospitals could be the focal points for such efforts.

Current Massachusetts leaders in imaging and sensing include Raytheon and MITRE.

COMPETITIVE POSITIONING OF MASSACHUSETTS

Indicators of Strength

Massachusetts has broad academic strength in imaging related fields as well as IT and robotics that underpin systems applications.

- Massachusetts rates very highly in publications levels and citation rates for key fields related to imaging and sensing:
  - Optics and acoustics — Massachusetts institutions produced 6.5 percent of U.S. publications and were cited 99 percent more than the national average.
  - Radiology, nuclear medicine, imaging — each of three Massachusetts institutions was cited at least 50 percent more than the national average.
  - Spectroscopy — 74 percent higher citation rate overall, with research at each of four institutions (Harvard, Tufts, Northeastern and UMass Amherst) being cited at least 50 percent more than the national average.
- Academic strength in systems includes:
  - Artificial intelligence, robotics and auto control – Massachusetts overall produced almost 8 percent of U.S. publications, cited 129 percent more than the national average; a broad position in research at each of four institutions (UMass Amherst, Boston University, Harvard and MIT) was cited at least 50 percent more than the national average
  - Information technology and communication systems – Massachusetts overall produced 6.4 percent of U.S. publications; MIT leads the nation in overall publications, Boston University is 13th, and UMass Amherst is 18th (the UMass system is 16th).

Examples of Leading Initiatives in Other States

The National Science Foundation has funded a number of centers in sensor-related areas. Beyond the Northeastern University-based CenSSIS Engineering Research Center, others include the Center for Embedded Network Sensing at UCLA (an NSF Science & Technology Center); the UC Berkeley Sensor and Actuator Center focused on wireless microsensors; and the Center for Sensor Materials at Michigan State University focused on vehicular sensing systems.

DOE national labs also bring significant strengths in sensing technologies and developing sensing systems, as do many of the military research centers.

SPECIFIC ACTIVITIES AND STATE SUPPORT REQUIRED

- One important way to begin to link and focus these capabilities is to develop a unique test bed facility for advancing sensor networking technologies, connecting the full range of sensors from infrared to microwave to RF to ultra-violet.
- Develop a series of signature facilities pursuing leading edge applications, such as millimeter and submillimeter wave technologies and multi-load sensors capable of flipping back and forth between different modes. The facilities would be established across multiple institutions with industry links and a coordinating advisory board. Given the sophisticated requirements for sensing research facilities, involving specialized clean rooms and costly equipment, it is expected that new facilities would be very expensive, costing in excess of $50 million.
- Provide a one-stop approach to access a broad base of researchers and technology capabilities found in Massachusetts for industry and university collaborations, stressing the common challenges across sectors. Actively promote Massachusetts as the location for industries needing to develop sensing and imaging-based solutions.
- Given that the potential uses of these technologies span several sectors—defense/warfare, homeland security, medical and environmental—an effective approach to securing funding may be to organize around and champion a specific industry-based application such as information-based warfare or image-guided therapy in medicine.

CONCEPT PAPER:

"Go-to" X-ray Laser Facility for Next-Generation Imaging

THE OPPORTUNITY

Establish a one-of-a-kind large national user "X-ray laser" facility that will advance Massachusetts' leadership in next generation imaging technologies, impact broad fields of science, create new talent pools, and attract on-site industry participation.

X-ray laser technology is the next generation of accelerator-based technology. It offers the revolutionary capacity to observe molecular changes in real time, and is expected to lead to major new breakthroughs in biotechnology and nanotechnology-based materials development. The cost of such a facility is significant – exceeding $300 million. It is likely that only one location in the U.S. will garner the federal support needed to establish such a facility. Massachusetts has an opportunity to be the home for this facility, led by the expertise and track-record of MIT, combined with the broader scientific base found in Massachusetts for advancing applications and commercializing innovative discoveries resulting from this X-ray laser technology.

Industries affected

IT, Telecommunications, Biotechnology, Medical Devices, Advanced Manufacturing

Regions affected

Greater Boston, Northeast, Central, Western

Total investment required

Low Med **High**

Federal support available

Low Med **High**

Payoff for Massachusetts

Low **Med** High

CONTEXT

Key advances in genome-related protein and protein complexes, semi-conductors, and advanced materials have depended upon modern condensed matter research. The next generation of this research will go beyond the current observations of static phenomena to allow for real-time observations of events. As an Organization for Economic Co-Operation and Development (OECD) Global Science Forum Report on Large Facilities for Studying the Structure and Dynamics of Matter explains: "Scientists now know that a full understanding of many processes cannot be achieved by considering initial and final states alone, but must incorporate the role played by intermediate states (often extremely short-lived ones) and the transitions between them."

X-ray lasers are at the forefront of this next generation of technologies able to focus on real-time observations of the evolution in time of atomic motions and chemical reactions of condensed matter or, in layman's terms, enable dynamic molecular imaging.

The significance of establishing this next generation is that it will enable new types of scientific measurements and applications informed by a greater understanding of the dynamics or temporal dimensions of physical, chemical and biological processes. It will have significant impacts on material sciences, protein structure measurements, and various fields of engineering. One might determine the structure of a single molecule with one x-ray pulse without the need for crystals; probe the dynamics of atoms, molecules or condensed matter on fundamental time scales and length scales simultaneously; study the properties of matter at very high energy densities; improve technologies for fabricating, inducing and observing structure at the smallest length scales; and probe and exploit non-linear phenomenon in the x-ray regime. And it will be an exquisite tool to manipulate matter as well.

ECONOMIC BENEFITS – potential size of relevant markets

It is difficult to fully account for the market potential, because as the OECD report suggests, "the inherent difficulty of predicting breakthroughs in science…thus a decision on a new facility may require a 'leap of faith' and an assumption that a vastly increased source capability [such as an x-ray laser facility] will lead to new, exciting advances in scientific measurements and applications."

FEDERAL FUNDING PROSPECTS

There is widespread scientific interest to advance an x-ray laser facility, as pointed out by the OECD report. In the U.S., the National Science Foundation, Department of Energy and DARPA are potential funding sources. It is expected that one federal agency will take the lead, but that is still to be determined.

TIME FRAME

The development of a large user facility is a long-term undertaking and will involve several phases of activity. The initial phase, which could take up to two years and a major investment, would involve developing a conceptual design, scientific case and R&D plan as well as a cost estimate and construction schedule. The construction phase would take several years.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

MIT brings a strong scientific capacity in accelerator technologies and laser technologies, and is one of the few institutions able to attract such a facility. MIT currently operates the Bates Linear Accelerator Center, a DOE-funded laboratory on an 80-acre campus in Middleton, 20 miles northeast of the main MIT campus. The Bates Lab has a distinguished research track record including understanding deformed nuclear structures using high resolution electron scattering in the 1970s, pioneering experiments on light nuclei in the 1980s, and studying of proton structure using parity violating electron scattering in the 1990s. It has also been a major center for education and training of physicists with over 110 PhDs having based their doctoral research at the Bates Lab.

Potential for Industry Linkages

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 and pharmaceutical companies interested in genomics and proteomics, as well as companies involved in nanotechnology-related materials development, many of which will be new start-ups in Massachusetts.

COMPETITIVE POSITIONING OF MASSACHUSETTS

Indicators of Strength

MIT is ranked 1st in the nation in physics along with CalTech by *US News & World Report*, with Harvard tied for 3rd.

- In condensed matter physics, MIT is ranked 2nd and Harvard 8th.
- In atomic/molecular/optical/plasma physics, MIT is ranked 1st and Harvard 4th.
- In elementary particle/nuclear physics, MIT is 2nd and Harvard 6th.

In total citations in physics from 1997 to 2001, MIT is ranked 1st, Harvard 7th and Boston University 18th.

In total citations for applied physics/condition matter/material sciences from 1997 to 2001, MIT is ranked 1st and Harvard 18th.

Examples of Leading Initiatives in Other States

Although a leading contender for this facility, MIT faces competition from at least two other powerful institutions, 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 active support of the state of Illinois.

SPECIFIC ACTIVITIES AND STATE SUPPORT REQUIRED

- Development of a one-of-a-kind large user facility for researchers in Massachusetts and from across the nation and globe, who would come to the facility to conduct their research.
- Active engagement with industry on a "contract basis" as well as cooperative research agreements and active commercialization program for new venture development. A similar type of facility—based on older generation technology at Argonne National Laboratory—had 54 cooperative research agreements, 74 contracts for use of the facility and 128 active licenses in place in FY 2001, with approximately a third of the activity with in-state industry.
- Educational programs for development of leading scientists and engineers in accelerator science and technology in Massachusetts as well as unique outreach programs at the K–12 level for Massachusetts students and teachers.

There is a need for significant matching funds if Massachusetts is to succeed in being the site for this large x-ray laser user facility. In Illinois, where Argonne National Lab is located, the state has contributed significant funds over time, which have leveraged considerably greater federal investments, including:

- $20 million for a sophisticated "guest house" for visiting users
- $17 million to attract an $850 million DOE investment for next-generation Rare Isotope Accelerator in competition with others
- $13 million that matched federal earmarks to support construction of the Argonne Nanoscale Center—a multi-university collaboration—with active industry involvement.
- Invested state funds for early stage product development and venture development relating to technologies being commercialized in conjunction with Argonne.

CONCEPT PAPER:

Integrated Communications-IT Platform for Emergency Response and Command and Control

THE OPPORTUNITY

> ***Ensure Massachusetts' continued technology leadership in the development of next generation systems for the integration of communications and information technology through inter-disciplinary and multi-institutional teams brought together with shared test bed facilities.***

Create a unique capability related to Homeland Security and Command/Control defense needs to develop a next generation platform for integration for emergency response systems and for command/control defense systems, involving sensing, networking/communications, information management and decision-making.

Industries affected
IT, Telecommunications, Defense

Regions affected
Greater Boston, Southeast, Central, Western

Total investment required
Low Med High

Federal support available
Low Med **High**

Payoff for Massachusetts
Low **Med** High

CONTEXT

There is a need for developing next generation of data/communications systems—which are in fact a system of systems—and make these systems more flexible and less dependent on point-to-point communications, so it can enable real-time, distributed decision-making. Some have coined this need advancing "complex adaptive systems" because no system can stand alone, and there is a need to advance system-to-system interactions which can trigger specific decision-making processes. At its basic core, these complex adaptive systems must be capable of fusing data from multiple sources, communicating this information and applying this information into simulation and other predictive tools to provide decision guidance and support as well as training exercises.

This is a core problem for defense in which each of the military services have multiple systems that need to be integrated in real time as well as need to be accessible to other branches of the military. There is a particular need in defense-related command control systems for better "simulation" models of the dynamics involved with changing networks and entities coming in and out of the network, such as different aircraft, ground forces, etc. There is also a key need in the defense sector for "transformational communications" in which information can be moved in a more distributed manner rather than point-to-point, as well as for advanced systems in information analysis that allow powerful "question/answer" search engines to cut across large, complex databases.

This need for next generation data/communications systems is also found in homeland security. A critical current unmet need is the ability to connect, and manage in an integrated manner, the functions (protection, detection, analysis, communication, response management, and restoration), geographies (coastlines, borders, harbors, cities, communities, states, and federal entities), responders (police, fire and EMS), and applications (medical, transportation, power, communication, air, water, and food supplies). There is also substantial development of new capabilities in detection and monitoring.

ECONOMIC BENEFITS – potential size of relevant markets

In a relatively short time, homeland security has become a major government and commercial market. It is estimated that the homeland security market in 2003 reached $52.5 billion in government spending, with another $18 billion in marketplace security activities (securing physical sites) and $15 billion for IT security/contingency. A broader view sees as much as another $90 billion in the commercial homeland security market driven by insurance and supply chain reengineering and monitoring.

Still, this is an emerging market that can take several directions. Key market drivers include government spending, government legislated requirements and future events. It is anticipated that the federal government will be a key funder for years to come. The level of commercial interest and funding is yet to be determined (this is an embryonic commercial market segment.)

Defense is also a growing market, where U.S. military superiority requires greater and greater applications of sophisticated command and control processes to be able to fight smarter and more effectively.

Over time, there is expected to be significant commercial application—enabling improved drug development, enhanced medical care and greater use of the "semantic web"—whereby people can manage day-to-day activities at work and at home, tapping into a multitude of databases and interacting via web-based communications with devices in our home and office.

FEDERAL SUPPORT AVAILABLE

One primary funding source is the newly formed Department of Homeland Security, which has a growing university centers program. NIH, EPA and DOT might be other supporting funding agencies to pursue.

From a more defense-related perspective, U.S. Air Force Research Laboratory and DARPA funding related to battlefield communications systems involving network of networks, robust, self-healing networks and data mining/pattern recognition.

TIME FRAME

Homeland security funding has begun within the past year and is quickly ramping up. Major initiatives will be awarded and funded over the next several years.

Next generation of command and control—including specific advances in networking, systems-to-systems engineering and multi-media information analysis—is a continuing research need for all branches of the military and DARPA.

"FIT" WITH MASSACHUSETTS

Key Ongoing Massachusetts Research Drivers

Many key activities are going forward in complex networks and detection activities in Massachusetts, which call for a broader integration platform to be able to collect, distribute, analyze and act upon that information.

Examples include:

- Hanscom/MITRE expertise found across all areas of command and control, including sensors, networking/communications, information management and decision-making. Maintains significant interactions with commercial companies developing new technologies, as well as deep connections with academic institutions, such as MIT, UMass Amherst, Brandeis, and other Massachusetts research institutions.
- Lincoln Laboratories brings significant strengths in sensors and sensing, communications and advanced electronics and developing advanced engineering solutions with primary focus on national defense.
- UMass Amherst brings strengths in both networking and detection technologies through its computer science

and electrical engineering departments. It is developing a broad-based sensors network platform for detection and managing information through its newly funded ERC for Collaborative Adaptive Sensing of the Atmosphere, which combines advances in microwave technologies with next generation computer networking.

- MIT has significant strengths in computer science and electrical engineering central to developing next generation IT/communications platforms, with ongoing activities in data fusion, analysis, modeling and simulation, prediction, and communication. Of particular note are the Research Lab for Electronics—one of the oldest and largest MIT interdisciplinary research centers, involved in communications, signal processing, and language—and the recent merger of the Lab for Computer Science and the Artificial Intelligence Lab into a decision support lab.

Another strength is the medical facilities for emergency response at major teaching hospitals in the Boston area, with some of the nation's leading emergency medicine departments. Beth Israel Deaconess has a focus on medical informatics and has implemented real-time, information technology-based management of its emergency medicine department. Partners HealthCare facilities have leading-edge telemedicine capabilities. Also, UMass Worcester and the Baystate Health Systems bring emergency response capabilities for central and western Massachusetts.

Potential for Industry Linkages

There is a strong potential for industry collaborations in the development of next generation systems for the integration of communications and information technology given the strong presence of defense contractors, computer networking firms, and telecommunications firms.

COMPETITIVE POSITIONING OF MASSACHUSETTS

Indicators of Strength

Massachusetts stands out in its computer science strengths, with MIT, Harvard and UMass Amherst ranked among top programs in computer science by *US News & World Report*. Particular computer science niches where Massachusetts institutions are ranked among the top ten include computer engineering at MIT (1st); computer systems at MIT (2nd); artificial intelligence at MIT (1st) and UMass Amherst (6th). Also, Boston University and Harvard are among the top 25 universities in total citations in artificial intelligence.

Massachusetts institutions are also among the leaders in IT and communication systems. In total citations, MIT ranks 1st, Boston University 13th and UMass Amherst 18th for this field of research.

MITRE and Lincoln Labs are among the leading federally-supported research centers focusing on command and control issues.

Examples of Leading Initiatives in Other States

A number of university consortiums are being developed relating to homeland security. Texas A&M has developed a collaboration with UNM, LSU, and others. Ten or eleven New York universities have developed a partnership to seek grants.

Key competitor institutions in IT and communications and computer science excellence include Stanford/UC Berkeley, Carnegie Mellon and Pacific Northwest Labs in Washington State.

SPECIFIC ACTIVITIES AND STATE SUPPORT

Establish multi-disciplinary and cross-organizational teams, test bed facilities to use Massachusetts and New England as a national pilot with strong user (police, fire, hospitals, etc.) involvement and defense-related participants (Hanscom, MITRE, defense contractors).

CONCEPT PAPER:

Industrial Biotechnology and Clean Technologies

THE OPPORTUNITY

> ***Enable Massachusetts-based commercial development of new products and processes applying industrial biotechnology and clean technologies that offer benefits of high productivity, low environmental impact, and robust design.***

Industrial biotechnology and clean technologies, such as green chemistry and bio-nanotechnology, offer the potential of significant benefits for advancing industrial activity in Massachusetts. First is the need to develop products that command a premium because of their unique features. If products cannot command a premium, they will not be produced in Massachusetts. Second, if products are to be produced in Massachusetts, they must be seen to pose limited dangers to the environment and health. Manufacturing in Massachusetts is limited not just by labor costs, but, more importantly, by the cost of establishing a plant in this state—the cost of complying with health and safety regulations. These regulations are driven by concerns about the health and environmental effects of industrial processes. Third, terrorism has raised concerns about the safety of industry facilities, chemical plants in particular. The only cost-effective way to meet these concerns is to design plants and products that do not pose dire threats to health and environment if attacked.

Industries affected
Advanced Manufacturing, Environmental Technology and Services, Specialty Chemicals, Renewable Energy

Regions affected
Greater Boston, Northeast, Central, Western

Total investment required
Low Med High

Federal support available
Low Med High

Payoff for Massachusetts
Low **Med** High

CONTEXT

The development of these technologies requires expertise drawn from a range of disciplines and research in fields that are still emerging. Massachusetts universities have developed strengths in a broad array of fields including nanotechnology, materials science, and green chemistry. Establishing a focal point for interaction among university researchers and company staff through the development of specialized user facilities is needed to integrate research efforts and demonstrate technological capabilities. Demonstration capabilities are critical to moving new technologies to commercial development.

Another key factor in moving technologies to commercial development in a number of fields is validation. The advantages of these innovative products and processes must be validated through testing and evaluation to gain market acceptance. University researchers would work closely with industry and federal and state regulatory agencies to develop appropriate methodologies for testing and evaluation of new products and processes. This effort would significantly reduce the barriers to commercial development by reducing uncertainty and risk for companies.

ECONOMIC BENEFITS – potential size of relevant markets

The potential benefits to Massachusetts from investments in industrial biotechnology and clean technologies is suggested by the size and growth potential of three broad markets—specialty chemicals and materials, renewable energy, and environmental technology and services. Many of the industrial biotechnology-related applications will offer multiple options for upgrading industrial manufacturing processes, improving their efficiency, lowering energy requirements and minimizing environmental waste.

- Massachusetts enjoys a strong position in **specialty chemicals and materials**. It is in this segment of the chemical industry that many industrial biotechnology-related products and processes will be developed, particularly for alternative plastics production and for biocatalysts used in chemical manufacturing processes. The U.S. market value for alternative chemical end-use products was $35.8 billion in 2002 and is estimated to generate a market value of $49.15 billion in 2007, which represents an overall AAGR (average annual growth rate) of 6.5 percent over the next five years. The alternative plastics market was valued at $6.5 billion in 2002 and should increase substantially to $10.85 billion by 2007, which represents an AAGR of 10.8 percent.
- In the case of **renewable energy** technology, Massachusetts enjoys growing positions in fuel cell technology and solar power. Massachusetts' strength in fuel cell technology is in the area of small, portable power units. This segment of the market is relatively small, but is projected to grow to $5–$10 billion by 2020. Massachusetts is already a leader in the discovery and increasing development of biobatteries applying microbial-based biotechnology, and is actively advancing solar based technologies using advances in polymer-based nanotechnology.
- More broadly speaking, industrial biotechnology and green chemistry offer significant advances for environmental technology products. An important area for Massachusetts is **water quality**. The state is home to a range of technology firms devoted to water quality producing systems and services for waste water treatment, groundwater remediation, etc. This field also takes advantage of Massachusetts' strength in materials.

The total value of the globally installed base of advanced wastewater systems was estimated at $3.5 billion in 2001. This market is expected to grow at an AAGR of 5.5 percent to reach $4.6 billion by 2006.

Membrane technologies are well suited to the recycling and reuse of wastewater. Membranes can selectively separate components over a wide range of particle sizes and molecular weights. Globally, membrane systems for wastewater treatment are projected to increase in value over the next five years at 6.8 percent per year on average. The total U.S. membrane market was estimated at $1.6 billion dollars in 2000, growing at an AAGR of 8.3 percent, reaching nearly $2.4 billion by 2005.

Reverse osmosis (RO), used mainly for water desalination, also is valued for final filtration in effluent treatment, closed loop processes and the production of high-purity water for laboratory use and semiconductor manufacture. The market, valued at $238 million, is increasing at 8.3 percent annually. A subset of RO, nanofiltration (NF), or "leaky" RO, bridges the pore range between RO and UF. With $33 million in sales, NF membranes are used in applications that take advantage of their solvent stability. The RO and NF markets are expected to grow at a combined AAGR of 7.9 percent, thereby totaling $397 million in 2005.

Ultrafiltration (UF), a $248 million market, is growing at an AAGR of 7.6 percent. Widely used in the booming pharmaceutical and biotech fields, UF membranes continue to improve and find new applications. Inorganic membrane materials and moving modules are helping address the persistent problem of UF membrane fouling. Microfiltration (MF) membranes, used mainly in drug and electronics manufacture, are a $707 million business growing at 9.0 percent on average per year. MF membranes also dominate in the expanding field of medical membrane devices such as hemodialyzers, blood oxygenators, IV filters and diagnostic kits. Together, UF and MF amount to the largest market and also have the highest AAGR of 8.7 percent during the forecast period.

FEDERAL FUNDING PROSPECTS

There are no large federal funding sources dedicated to work in this area. Support must be patched together from among a range of federal agencies depending on the nature of technologies and industries engaged. Likely sources of federal funding include:

- EPA supports research concerned with reducing environmental impacts of manufacturing and pollution remediation. More specifically, the EPA administers a portion of National Nanotechnology Initiative research funds that it directs to research in these areas.
- DOE provides support for fuel cells and has a major program supporting research in catalysis, a key area for work in chemicals as well as fuel cells.
- DoD supports research in robust, portable energy sources.
- NSF offers potential funding through its environmental programs and engineering research centers.

TIME FRAME

Initial state lead investment efforts can be undertaken in the immediate to near term to position Massachusetts as a leader. Given existing funded research programs, such as in biobatteries, it is expected that having new capacities will quickly translate into new federal funding opportunities, though perhaps not a broad center basis.

A longer lead time is needed to position Massachusetts for a major federal center through NSF, EPA or the Department of Energy.

"FIT" WITH MASSACHUSETTS

Key Massachusetts Research Drivers

Many key activities in Massachusetts could be coordinated to enable the development of next generation products and processes and support workforce development.

- UMass Amherst is performing research related to biomass energy production and has a green chemistry capability growing out of its worldclass polymer research efforts involved in development of renewable feedstocks for polymer applications, solventless coatings and supercritical fluids to replace organic and/or toxic solvents in polymer processing.
- UMass Lowell offers capabilities in design for environment, such as biodegradable polymers and the reduction of toxics used in processes and products. These capabilities are complemented with a tradition of applied technology research in close connection to regional manufacturing firms.
- UMass Boston has a large and growing Green Chemistry program focused on solar energy conversion, energy storage, environmental chemistry for pollution sensors and water purification, and improved environmentally sound methods to use chemical processes or products. UMass Boston has also applied for an Innovation Partnership grant from NSF (with MIT/UMass Lowell/individual energy firms) that would include training for students.
- UMass Dartmouth, through its School for Marine Science and Technology (SMAST), has been active in coastal systems focusing on quality of water supply and developing solutions to address the growing ecological degradation of coastal ecosystems.
- WPI is home to the Fuel Cell Center (FCC). The FCC is a university-based research program with industry members paying between $2,500 and $25,000 per year. Built primarily around chemical engineering faculty, the FCC undertakes research on technologies for stationary and portable fuel cells.
- MIT has a number of interdisciplinary programs reaching across environment and energy such as its Laboratory for Energy and the Environment and its Center for Materials Science and Engineering.

Potential for Industry Linkages

University-based efforts to support next-generation product development should develop connections with the water quality sector, specialty chemical companies, and the emerging cluster of renewable energy companies.

The cluster of renewal energy companies in Massachusetts and New England includes companies working on fuel cells, solar power, and biomass. Specific companies involved might include: Evergreen Solar, Inc., Konarka, Camp Dresser McKee, RWE Schott, and General Electric.

Of these groups, specialty chemicals is perhaps the most promising. Companies in this industry command a premium. They tend to be larger firms with the willingness and ability to fund R&D at the universities.

COMPETITIVE POSITIONING OF MASSACHUSETTS

University Research Strengths

Massachusetts has key cross-cutting academic research strengths in microbiology-based biotech, materials, physics and chemistry fields that underpin a robust position in a number of industrial biotechnology and clean technology areas.

- Microbiology – Massachusetts has an outstanding leadership position in microbiology representing 7.25 percent of all publications in the field and significant research excellence with a 96 percent higher rate of citations per publication. Among the leading institutions of research excellence are UMass Amherst, UMass Worcester, Tufts, and Harvard.
- Organic chemistry and polymer science – in this field, closely related to materials strength in Massachusetts, Massachusetts produces over 6 percent of U.S. publications overall and three institutions rank in the top ten in terms of total publications—MIT (#1), UMass Amherst (#5) [UMass system (#2)], Harvard (#10).
- Environmental engineering/energy – research in Massachusetts overall is cited almost twice as much as the national average; research at both MIT and Harvard is cited at least 50 percent more than the national average and MIT leads the nation in total publications; MIT is ranked 7th in the nation in overall reputation in this field.

Examples of Leading Initiatives in Other States

The Michigan Biotechnology Institute is an example of a program focused on industrial biotechnology. It combines a range of integrated activities involving technology assessment, proof-of-concept, venture formation and incubation to advance new commercial applications. It was featured by Burrill & Company in its 2001 review of the biotechnology industry as developing new industrial products made from agricultural resources, resulting in the launch of eleven new bio-based companies. Among the types of products being advanced are coatings, renewable fuel co-products and biocatalysts.

At a statewide level, an example of an encompassing program in the broad area of industrial biotechnology and clean technologies is Ohio's support for small-scale fuel cell technology. A university-based initiative at Case Western University is undertaking an interdisciplinary research approach to advance fuel cell technologies. The Yeager Center for Electrochemical Sciences (YCES) promotes and coordinates research and education in electrochemistry. Research is focused on building miniature fuel cells using microfabrication techniques. The Yeager Center's work is taking place in the context of major state support for fuel cell technology in Ohio. The Ohio Board of Regents created the Ohio Eminent Scholars Award to support a new initiative in chemical engineering that focuses on fuel cells and micro power. The first Eminent Scholar, a leader in fuel cell research at Los Alamos, will be co-director of the Case Advanced Power Institute (CAPI). Ohio is seeking to build on its technical infrastructure for fuel cell research at multiple institutions, including Case Western Reserve University, NASA, Battelle, The Ohio State University, and Wright-Patterson. Moreover, the state is trying to strengthen the whole pathway to commercialization, from R&D to commercialization. Toward this end, the governor proposed a three year, $100 million dollar initiative in May 2003. Three quarters of the funds are targeted to low cost financing for manufacturers and users. The balance will be used to fund R&D and demonstrations. Three million will be set aside for training a skilled work force.

SPECIFIC ACTIVITIES AND STATE SUPPORT REQUIRED

Enabling the commercial development of the next generation of industrial biotechnology and clean technologies in Massachusetts will require the creation of an integrated infrastructure.

- Establish university-based facilities including specialized laboratories and testbeds for demonstrating and validating new industrial biotechnology and clean technologies. An example would be shared use development and validation facilities for biobatteries and green chemistry instrumentation facility equipped with high field NMR and surface microscopy labs. These facilities would be open to companies that would participate in R&D through a mix of common-pool membership and company-specific projects.

  State support: The absence of dedicated federal funding in this area makes an initial investment in facilities by the state imperative. It is only then that more narrowly oriented federal funding may be won and combined to pursue center objectives.

- Develop consortia to facilitate communication and research among key academic disciplines and industry sectors (plastics, renewable energy, chemicals) to identify and develop new products. Consortia may be built around the activities of industry associations like SEBANE (the Solar Energy Business Association of New England).

  State support: The development of these consortia may be aided by state support for regional business development organizations that often play an important role in convening industry and facilitating networking among regional companies.

- As the center develops and become connected to particular technologies, the logical next step is to develop curricula for training students at different levels to provide the skilled workforce needed for future industry growth.

CONCEPT PAPER:

Ocean Exploration and Management R&D Consortium

THE OPPORTUNITY

Organize a consortium of Massachusetts universities, research organizations and industry involved in ocean research and development to establish a new federally-funded research center with an initial focus on homeland security applications of ocean exploration and management research, followed by the development of a broader range of applications from ocean research.

New technologies for observation and detection in the ocean are an area of growing attention involving sensor systems, underwater vehicles and modeling technologies. These technologies are at the heart of an expanding focus of interest in the ocean for research and homeland security purposes as well as continuing for cost effective management of fisheries and coastal areas.

CONTEXT

At the research level, a recent report from the National Research Council, a bellwether of future federal R&D investments, has called for a large-scale, integrated program of ocean exploration. NSF already has underway an ocean observation initiative and NOAA has active programs in ocean research.

At the same time, homeland security of U.S. ports, coastal areas and cargo-bearing ships is a growing, near term need. And, ocean management is proving important for advancing the fisheries industry and ensuring its survival in Massachusetts.

ECONOMIC BENEFITS – potential size of relevant markets

Homeland security offers a major near term opportunity and requires higher performing remote observation and detection technologies.

The Department of Homeland Security (DHS) offers a new source of money for research and a large new source of funding for development. Not only could DHS money for research be won for challenging applications of new technologies, but links to a visible ocean research alliance in the right fields would help position Massachusetts companies for the far more substantial DHS money for developing new technologies and systems for security applications at ports and in coastal waters.

Although largely uncharted, marine biotechnology products and processes is already a major market, estimated at $2.4 billion in 2002, a 9.4 percent increase from 2001, by Business Communications Company, Inc. These existing markets include algae-based products, aquaculture, fish health, marine-based biopolymers, adhesion inhibitors used in protecting ships, and new types of adhesive "glues" for joining tissue, among others. Future advances from ocean exploration being actively pursued include new pharmaceuticals and environmental remediation.

Industries affected
Oceanographic, fisheries and defense/homeland security

Regions affected
Greater Boston, Southeast

Total investment required
Low Med High

Federal support available
Low Med High

Payoff for Massachusetts
Low **Med** High

FEDERAL SUPPORT AVAILABLE

The Navy has been an important funder of ocean research and ocean-related technologies. By one estimate, 85 percent of the research funding into marine technology comes from the Navy. A closely-related funding source that is now emerging is for homeland security, particularly through the Coast Guard with support from the Navy, for port security, defense of coastal areas and monitoring of cargo ships.

If the federal government takes its lead from the recent NRC report, major new funding could become available through a number of federal agencies. Likely supporters include the NSF and the National Oceanic and Atmospheric Administration.

Another opportunity is the prospect of major funding for a network of ocean observatories. This is a project that has been under consideration for funding through the NSF's fund for Large Research Facilities (facilities costing over $100 million).

Finally, NOAA's ocean exploration activities are another key source of funding.

TIME FRAME

The proximate opportunity is a center award from DHS.

Support provided through a center could be the basis for positioning Massachusetts for bidding on federal funds for ocean exploration if and when a major new federal program of support is mounted.

"FIT" WITH MASSACHUSETTS

University Research Strengths

- In aquatic sciences, Massachusetts shows its ocean related research excellence with an 88 percent higher rate of citations per publications, representing 7 percent of all publications in the field. Key leading institutions include Woods Hole, MIT, Boston University, Harvard and UMass.
- In total oceanographic research at universities and leading research institutions, such as Woods Hole, Massachusetts' ranks 10th in the nation.

Potential for Industry Linkages

Coastal corridor from Maine, Massachusetts and Rhode Island has one of the leading clusters in oceanographic companies involved in instrument development. It is particularly strong in sensors and ocean instrumentation as well as in underwater vehicles.

Linkages may be facilitated through the activities of an important industry association in this field—the Marine and Oceanographic Technology Network (MOTN). MOTN includes major industry players in the related technology markets, including Sippican and Raytheon, as well as WHOI and other research institutions in Massachusetts, UMass Dartmouth.

Fisheries remain an important industry for Southeast Massachusetts and have already significantly benefited from ocean research and management technologies.

There is also a potential tie-in with materials companies and biotech/pharmaceutical companies as research into diverse life forms and compounds emerge.

COMPETITIVE POSITIONING OF MASSACHUSETTS

R&D Drivers and Complementary Players

Major research activities across range of institutions:

- Woods Hole has more than 300 staff involved directly in scientific research with state-of-the-art facilities—from research vessels to analytical and instrumentation facilities to a deep submergence facility. It offers a comprehensive set of research programs ranging from physical oceanography to applied ocean physics and engineering to biological research in ecology and physiology of microbes to a geology and geophysics program and a marine chemistry and geochemistry program. Woods Hole brings many specialized centers and institutes, as well as collaborative efforts with universities including MIT, Boston University and UMass.
- Oceanographic research at MIT is closely linked to research into global climate change focusing on climate-related interactions of oceans and atmosphere through the Center for Global Change and the Program in Atmospheres, Oceans, and Climate, which draws heavily on expertise in modeling and simulation. MIT also has a strong focus on engineering applications in oceanography. Most notably, the DeepArch (Deep Water Archeology) research group is working at pioneering very high resolution sonar imaging of the sea floor. They are undertaking some of the most challenging problems in underwater robotics.
- UMass Dartmouth School of Marine Science and Technology (SMAST) is active in fisheries science research, autonomous underwater platforms, development of natural laboratories at Mount Hope Bay and Georges Bank, and management of coastal ecosystems, including bays, harbors, wetlands and watersheds.
- UMass Boston brings strengths in ecosystems, involving research into the interaction of coastal environment bacterial—plants in the biodegradation of pollutants, marine conservation, toxin effects on coastal ecosystems, novel biomaterials for antibacterials and adhesives and biodiversity in deep sea life.
- Boston University's marine center focuses on remote sensing, atmospheric sciences and earth sciences.

Examples of Leading Initiatives in Other States

The chief competitor to the proposed consortium is the University of California's Scripps Oceanographic Institution in La Jolla. The La Jolla campus is home to the Joint Institute for Marine Observation, a collaboration between NOAA and the University of California's Scripps Institution of Oceanography. The overall goal of the institute is to create a center of excellence in which state-of-the-art observation capabilities such as platforms (surface, subsea, and air/spaceborne), sensors, and systems architecture of both NOAA and Scripps are utilized to fill pressing research needs. The specific themes reflect the particular strength at Scripps in the areas of coupled ocean-atmosphere climate research, blue water and littoral oceanography, marine biology/biological oceanography, marine geology and geophysics, and ocean technology. It also lends the strength of the Scripps large fleet of surface and subsurface platforms to the success of observation-based science for NOAA. Scripps is also home to the Center for Marine Biotechnology and Biomedicine. The Center is integrated with the UC San Diego Medical School. A central research focus is the exploitation of marine organisms for novel compounds that may be used in new drugs, which is an important emphasis of the NRC report.

Another major player in California is the Monterrey Bay Aquarium Research Institute (MBARI). This organization could be a powerful ally in a California-based bid in the area of ocean observation technologies. MBARI is very much an engineering organization. Its number one "science and technology" goal is to "identify important areas of marine science where research progress is limited by lack of appropriate technology." Its deep sea research activities include MBARI Ocean Observing System (MOOS), remotely operated vehicle enhancements and upgrades, and new insitu instruments. MOOS is a long-term effort to translate the demands of answering a set of scientific problems into engineering systems.

Another potential competitor state is North Carolina. The University of North Carolina through its Institute of Marine Sciences has a long history of fisheries research. Moreover, the Beaufort-Morehead City area has one of the higher concentrations of marine scientists in the country. North Carolina State University and Duke University also maintain labs in the area. Other resources in the area include NOAA's National Ocean Service, which supports the Center for Coastal Fisheries Habitat Research and the North Carolina Division of Marine Fisheries.

Florida, meanwhile, has a leading center with the Harbor Branch Oceanographic Institute (HBOI) in Fort Pierce, Florida. The HBOI maintains a substantial fleet of research vessels. It also maintains strong engineering and production capabilities. HBOI's Engineering Division is recognized for contributions in the areas of ocean engineering and subsea systems, underwater imaging, oceanographic instrumentation, robotics, specialized tools, underwater sensors, program development and management.

SPECIFIC ACTIVITIES AND STATE SUPPORT

Competitive alliance. The first action that needs to be taken is to assemble a competitive alliance of Massachusetts institutions to compete for a DHS center. DHS is the proximate source of large-scale funding necessary to establish the beginnings of an organization that can anchor a larger R&D consortium supporting the development of ocean technologies. A center proposal might focus on developing an ocean observation system tailored to the DHS concerns about underwater threats to ports and coastal areas. It might be built around a complex of efforts including the Coast Guard's work with the Naval Undersea Warfare Center in Rhode Island.

State support: State matching funding for bid on DHS center.

Link technological capabilities. Second, the ultimate goal of linking technological capabilities with new markets can be addressed. A promising model for this process is the Center for Integration of Medicine and Innovative Technology (CIMIT). Supported by key Boston institutions, CIMIT is able to bring together academic clinical expertise with technical and engineering expertise in a highly focused and structured effort focused on key topic areas, in which a broad range of industry collaborations can be advanced from project-specific to industrial partnership to strategic alliance partners.

Institutional partners contribute financially to a common pool of capital, which is used to provide support on a competitive basis to university researchers and companies for the development of technologies in concert with customers. These projects are developed in a collaborative way through a multi-step process. To identify and promote new product ideas, CIMIT pays partial salaries to "site minders" at participating institutions. These site minders are active researchers, who keep abreast of developments and work with teams with promising ideas to develop research proposals for funding. These projects are then managed by a team that connects them with the relevant company players, IP advice and venture capital.

CIMIT enjoys a relatively congenial environment for development. The customers are the clinicians and hospitals that are members of CIMIT. The customers and markets cannot be so readily identified and engaged by the proposed Ocean Technologies Consortium—however, the integrated, iterative process of engaging stakeholders, expertise and capital offers some guidance.

State support: Seed funding from the state administered by UMass.

Access to capital for small firms. The ocean technologies industry is highly fragmented, composed largely of small firms. These firms lack the resources, including capital and infrastructure to pursue ambitious product development efforts. They need access to capital for projects not considered large enough by increasingly large venture capital firms. This is crucial not only for product development by local firms, but for keeping those firms local. If they do not have access to capital they may have to turn to larger firms outside the state, which will have no interest in Massachusetts-based development. These firms need access to infrastructure, such as docking facilities and ships for demonstration and field testing of product prototypes.

State support: State-subsidized leasing of docking facilities and ships. There exists a substantial pool of underemployed fishing vessels that maybe equipped and employed part-time for technology demonstration expeditions.

Five Ideas for Technology Connecting Initiatives

Technology Connecting Initiatives for Advancing Product Development and Regional Economic Development

Complementing the major strategic research alliances outlined in the previous section of this report is a range of technology connecting initiatives that can address specific gaps in the technology commercialization and product development processes, as well as ensure that Massachusetts reaps the downstream economic benefits from its significant research base.

The purpose of technology connecting initiatives is to translate university R&D capabilities into commercial development. In contrast, the purpose of strategic alliances is broader and has more dimensions to be considered.

Five possible technology connecting initiatives are discussed. Three concern commercialization in bioscience-related fields. The fourth is concerned with linking university R&D capabilities to the product development efforts of firms in a range of manufacturing industries in Massachusetts, and a fifth focuses on establishing a test-bed for information technology and communications collaborations.

The five technology connecting initiatives are the following:

- State-wide Bioscience Therapeutics Commercialization Entity
- Bioprocessing Consortium
- State-wide Medical Device Development Network
- State-wide Network of Product Development Centers to Advance High Value Manufacturing Partnerships
- Computer Grid Test-Bed for IT/Communications Technology Collaborations

State-wide Bioscience Therapeutics Commercialization Entity

THE OPPORTUNITY

Accelerate the development and commercialization of new drug therapies in Massachusetts by reducing the risks of early stage development faced by prospective company champions.

For a major biomedical research discovery to advance as a potential new drug requires significant drug discovery and development activities, often well beyond the scope of typical research programs. These activities include identifying a likely drug compound, advancing drug delivery approaches, conducting pre-clinical studies in animal models for efficacy and toxicity, and moving into early stage clinical trials.

GAP/MARKET FAILURE TO BE ADDRESSED

These days, as part of the corporate outsourcing of research activities, pharmaceutical industry is looking to reduce its risks and is actively pushing more of the initial drug discovery activities on its potential university partners, such as initial screening against libraries of drug candidates. At the same time, venture capital in therapeutics is seeking more sure bets, and is reluctant to invest in uncertain biological targets.

SPECIFIC ACTIVITIES AND STATE SUPPORT

A statewide bioscience therapeutic commercialization entity would focus 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.

Industries affected

Biopharmaceuticals

Regions affected

Greater Boston, Central

Total investment required

Low Med **High**

Federal support available

Low Med High

Payoff for Massachusetts

Low Med **High**

Bioprocessing Consortium

THE OPPORTUNITY

Capture the manufacturing activity of new "biotechnology" therapies, such as protein therapeutics.

Advances in biotechnology research are resulting in a growing number of new drug therapies produced by live, genetically-modified microbial or animal cells, referred to as biologics. *Genetic Engineering News* (August 2002) reports that the current total pharmaceutical market is $390 billion, of which biologics accounts for 7 percent. By 2006, the total pharmaceutical market is expected to increase to $550 billion, of which biologics will account for $70 billion—implying an annual growth rate for biologics of 15 to 20 percent.

The manufacturing of biologics involves complex and expensive scale-up manufacturing processes, and requires years to complete construction. The complexity and expense comes from the need to express the protein, purify cell lines, fill/label/package and maintain quality control over a very lengthy process. Moreover, there are strict regulatory requirements, referred to as Good Manufacturing Practices (GMP), which must be adhered to for production of these therapeutics.

Most emerging biotechnology companies lack the expertise to address the scale-up production issues, including the ability to comply with GMP regulations. Not surprisingly, there is also a shortage of facilities to produce these new therapeutics.

GAP/MARKET FAILURE TO BE ADDRESSED

In Massachusetts, there is a strong base of emerging biotechnology companies, but their focus and expertise is more on research and development and they lack the staff and technical resources for the complex process of biopharmaceutical manufacturing. A 2003 Massachusetts Biotechnology Council study, prepared by Boston Consulting Group, found that only 10 percent of the state's biotechnology companies were 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.

SPECIFIC ACTIVITIES AND STATE SUPPORT

Massachusetts must create 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; provide GMP training, building upon the base of efforts underway across universities in Massachusetts; and guide state investments in contract manufacturing facilities.

Existing research centers and facilities include: MIT's ERC for Biotechnology Processing, the Mass Biologics Lab, WPI's GLP bioprocessing center, and the GLP bioprocessing center at UMass Lowell.

Industries affected
Biopharmaceuticals

Regions affected
Greater Boston, Northeast

Total investment required
Low Med **High**

Federal support available
Low Med High

Payoff for Massachusetts
Low Med **High**

State-wide Medical Device Development Network

THE OPPORTUNITY

Expand and strengthen a unique university-hospital-industry complex supporting innovation in medical devices across the state.

Academia is an often critical element for advancing new medical device products. Clinicians are key for identifying needs and opportunities, while engineering and scientific research capabilities found in academia are important resources for the medical device industry, which is comprised of many smaller companies with niche market opportunities.

The biomedical device industry in Massachusetts is significant, and well positioned for continued growth. While Boston gets a lot of focus for its biomedical device presence, the medical device industry is also a key area of opportunity identified for Western Massachusetts and Central Massachusetts. However, these regions do not enjoy the same network advantages offered by the proximity of multiple institutions and capabilities present in the Greater Boston area.

GAP/MARKET FAILURE TO BE ADDRESSED

Historically, innovation in medical devices has been hindered by inadequate connections between clinicians who understand, first-hand, patient problems and the demands of medical practice and the engineering and commercial expertise of industry. Moreover, the medical device industry is fragmented, consisting largely of small firms. At the same time, innovation in medical devices demands the integration of complex arrays of technologies, a task that is beyond the capacity of such companies by themselves.

SPECIFIC ACTIVITIES AND STATE SUPPORT

Massachusetts must support the expansion and linkage of academic/industry networks developing across the state, which 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.

Industries affected
Medical Devices

Regions affected
Greater Boston, Central, Western

Total investment required
Low **Med** High

Federal support available
Low Med High

Payoff for Massachusetts
Low Med **High**

Key types of support can include:

- Grants for holding "innovation" forums bringing together clinicians, engineers and medical device companies around key topics for advancing new medical technologies on a regional and statewide basis.
- Developing a "capabilities" database of researchers and companies to promote collaborations.
- Sponsor time for academic "site minders" who actively identify opportunities for technology development and facilitate the development activities.
- Competitive commercialization grants for teams of clinicians, engineers and medical device companies to undertake prototype development. The grants are to be awarded on a competitive basis, based on market assessment and path to market, along with meeting match requirements (higher for larger companies). This will require production be done in Massachusetts or require repayment.
- Organizing an annual statewide purchasing fairs to connect supplier base with original equipment manufacturers.
- Supporting the organization of a similar statewide exposition that would highlight the resources and research capabilities of Massachusetts research institutions and academic health centers.

State-wide Network of Product Development Centers to Advance High Value Manufacturing Partnerships

THE OPPORTUNITY

Enable companies in core Massachusetts manufacturing industries to upgrade their development and manufacturing capabilities by establishing university-affiliated development assistance centers that provide systematic links with university R&D and talent.

The analysis of core focus areas suggests that there is a substantial base of advanced materials and electro-mechanical device (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 it goes about supporting these still significant industry drivers to remain world-class competitive with needed upgrading of process and products.

GAP/MARKET FAILURE TO BE ADDRESSED

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 Centers, and the UMass Dartmouth Advanced Technology and Manufacturing Center.

SPECIFIC ACTIVITIES AND STATE SUPPORT

Massachusetts should 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 focus of the product development centers would be responding to industry needs, but it 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, as has been done at 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.

Industries affected

Electro-mechanical Devices and Systems, Advanced Materials

Regions affected

Greater Boston, Central, Western

Total investment required

Low **Med** High

Federal support available

Low Med High

Payoff for Massachusetts

Low Med **High**

Computer Grid Test-Bed for IT/Communications Technology Collaborations

THE OPPORTUNITY

A Northeast Educational & Research Network is proposed to provide a platform for advancing high performance grid computing across Massachusetts, and create important linkages of Massachusetts to other networks.

There is a key need in Massachusetts to provide a broader educational and research network to enable high performance grid computing activities which connect across universities, teaching hospitals and industry in the state and to the broader New England and Northeast region.

Massachusetts has a broad base of industry focused on telecommunications, in which having 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 developing informatics software, middleware and data management for large scale, heterogeneous data that comprises modern biotechnology.

GAP/MARKET FAILURE TO BE ADDRESSED

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. But 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 currently not planned to be served by the new $100 million optical network called National LambdaRail offered by an academic consortium reaching from 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.

Industries affected

IT, Telecommunications, Life Sciences, Defense

Regions affected

Greater Boston, Central, Western

Total investment required

Low **Med** High

Federal support available

Low Med High

Payoff for Massachusetts

Low Med **High**

SPECIFIC ACTIVITIES AND STATE SUPPORT

A Northeast Educational & Research 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 are possible based on the specific application and the broad breadth of institutions that can be linked together.

The Massachusetts Technology Road Map and Strategic Alliances Study

Appendix:

Core Technology Charts
Glossary of Terms

Massachusetts' Ranking in Ten Core Technology Focus Areas

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

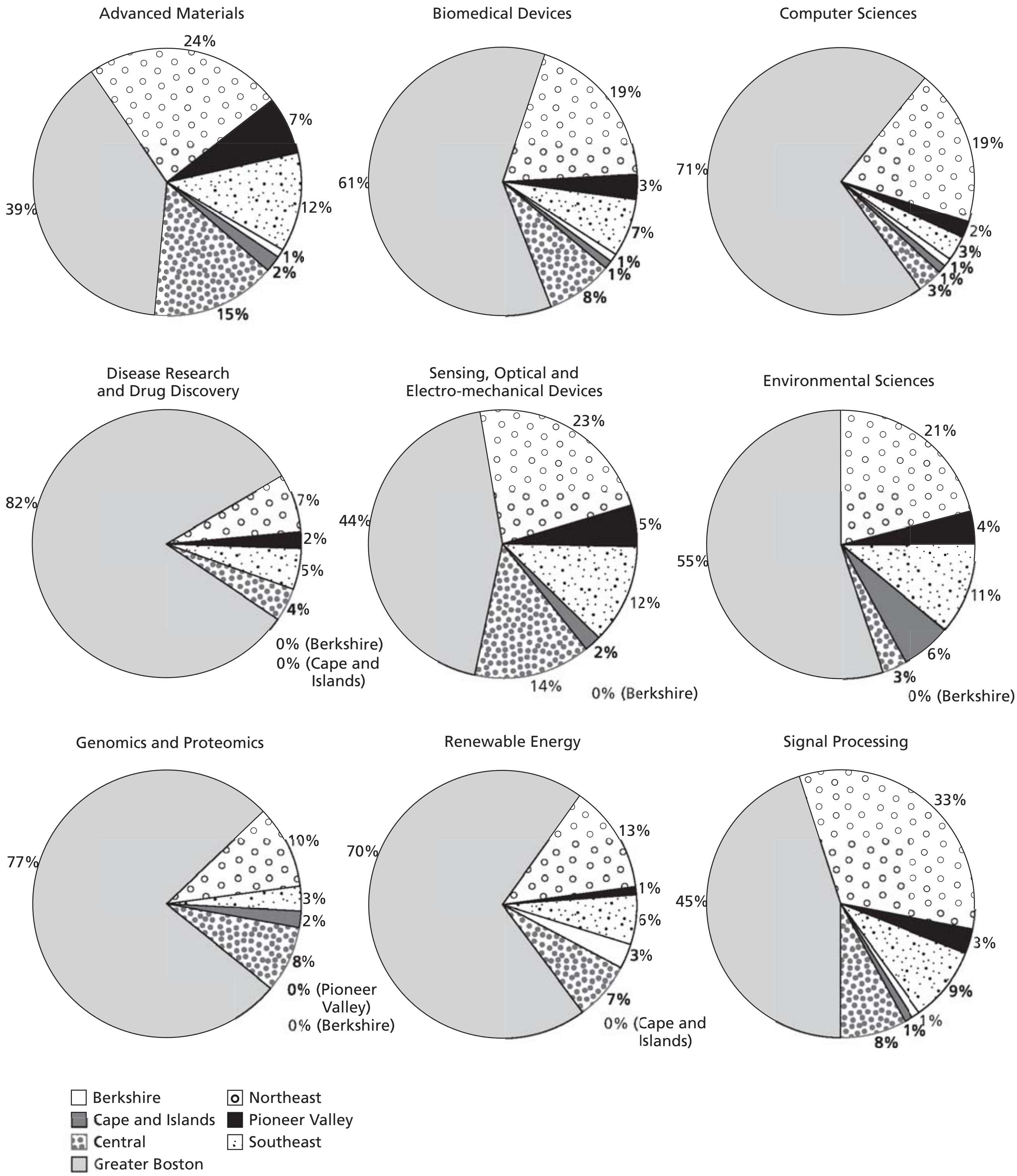
	INDUSTRY PRESENCE		TALENT GENERATION		RESEARCH EXCELLENCE	
	Number of firms	Employment controlled by Massachusetts firms	Total degrees awarded, 2001	Change in degrees awarded, 1996 to 2001	Total state funding in related-university research fields	Leading institutions in total citations (top 25 in nation) 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.

Refer to the charts that follow for more detail on each of these ten core technology focus areas.

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

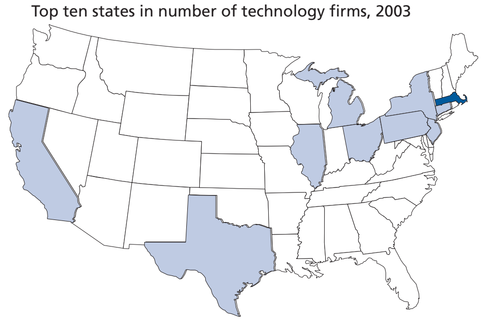
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Electronics	Coatings and multi-layer depositions Carbon nanotubes
Medical devices	Biomaterials
Metalworking	Advanced alloys Near net-shape light metals
Paper converting	Coatings and multi-layer depositions
Plastics	Polymer synthesis Processing 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

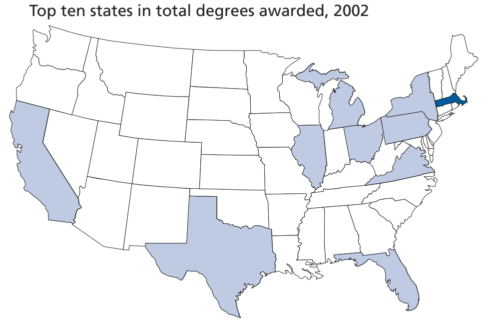
Top ten states in number of technology firms, 2003



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

Talent Generation

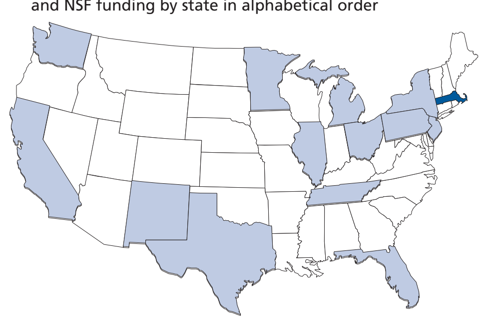
Top ten states in total degrees awarded, 2002



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

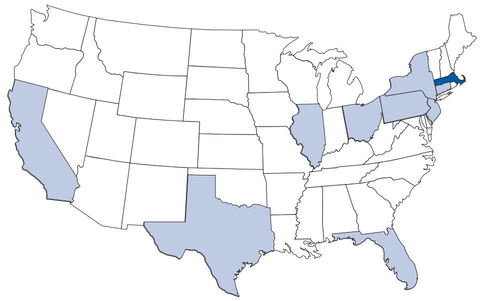
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Defense industries	RF technologies Micro-wave technologies
Telecommunications	Wireless communications Digital-analog switching
Computer hardware/ Electronic systems	Digital signal transmission, Amplification, Switching, Embedded network systems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

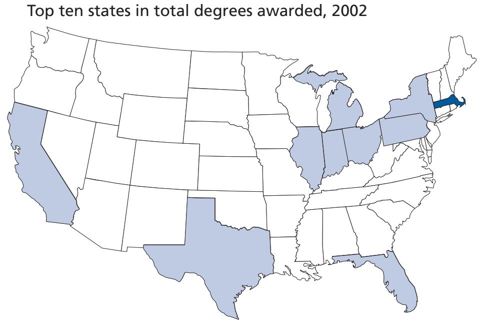
Top ten states in number of technology firms, 2003



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

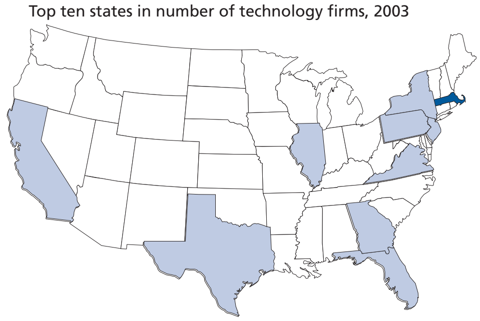
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Computer services	Data storage
Defense industries	Computer modeling and simulation
	Distributed systems
Health care	Computer security
	Computer networking
Financial services	Data mining and information retrieval
	Software applications development

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

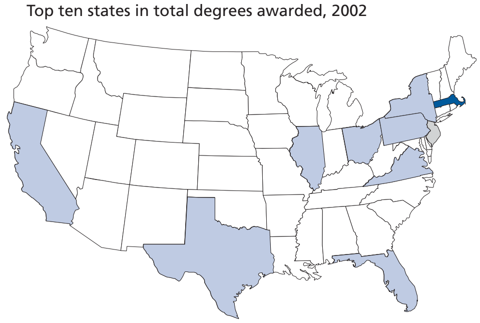
Top ten states in number of technology firms, 2003



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

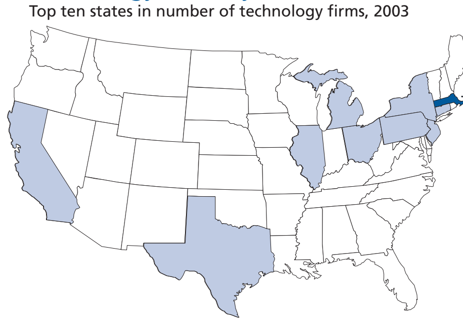
LEADING STATES

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**
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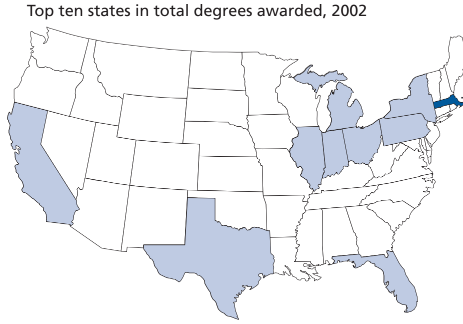
8. New Jersey
9. Connecticut
10. Michigan

Talent Generation

Top ten states in total degrees awarded, 2002



1. California
2. New York
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4. Michigan
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8. **Massachusetts**
9. Florida
10. Indiana

Research Excellence

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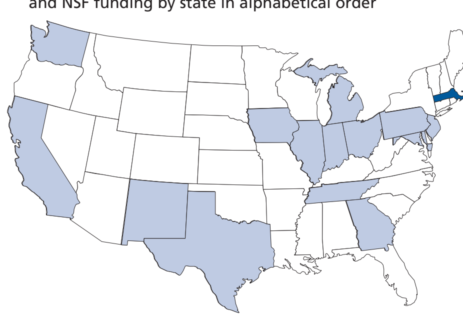


California
Georgia
Illinois
Indiana
Iowa
Maryland
Massachusetts
Michigan
New Jersey
New Mexico
Ohio
Pennsylvania
Tennessee
Texas
Washington

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

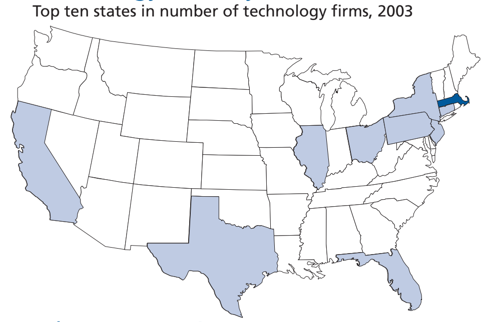
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Environmental engineering and protection	Water quality research Green chemistry
Oceanographic industry (often with strong defense connections for naval activities and increasingly homeland security applications)	Integrated sensing and information 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
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5. Connecticut
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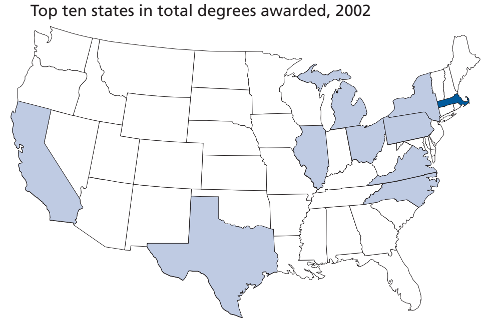
9. New Jersey
10. Florida

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

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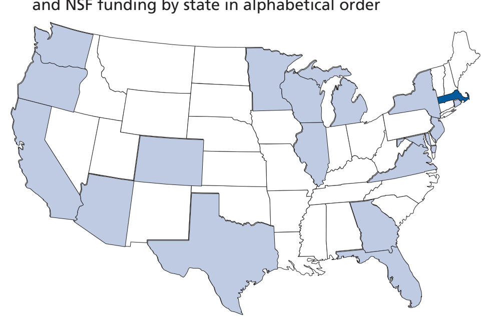


Arizona
California
Colorado
Florida
Georgia
Illinois
Maryland
Massachusetts
Michigan
Minnesota
New Jersey
New York
Oregon
Rhode Island
Texas
Virginia
Washington
Wisconsin

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

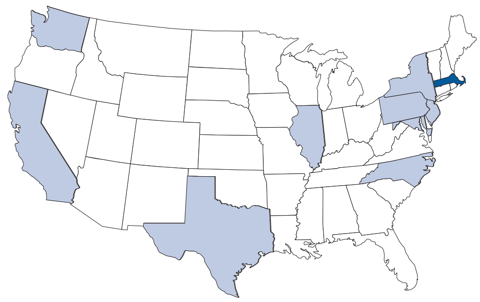
LEADING STATES

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

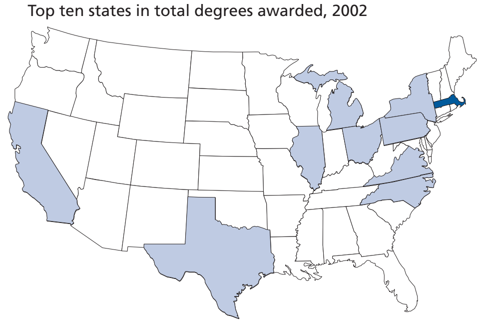
Top ten states in number of technology firms, 2003



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

Talent Generation

Top ten states in total degrees awarded, 2002



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

Research Excellence

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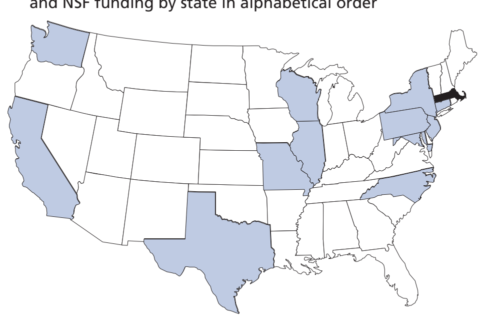


California
Connecticut
Maryland
Massachusetts
Missouri
New Jersey
New York
North Carolina
Pennsylvania
Texas
Washington
Wisconsin

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

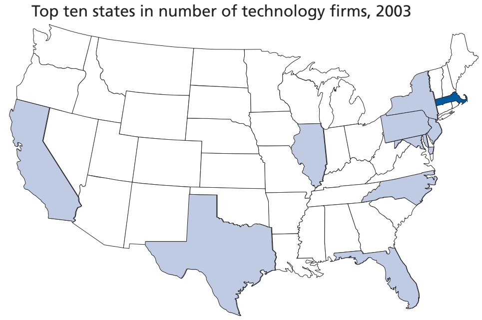
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Pharmaceutical industry Biotechnology industry involved in new thera-peutics development	Cluster activities in disease research found in: Cancer research, Cardiovascular research, Infectious diseases, HIV Neurosciences Patent activity in drug 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

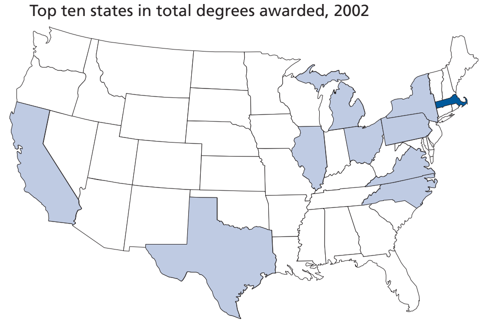
Top ten states in number of technology firms, 2003



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
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3. Texas
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5. Illinois
6. **Massachusetts**
7. North Carolina
8. Ohio
9. Michigan
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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

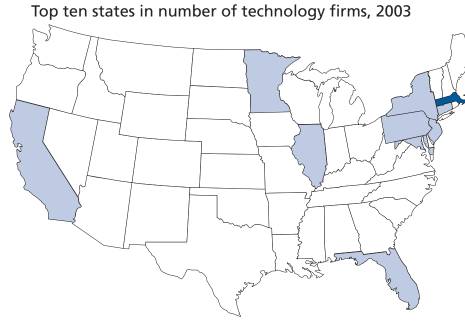
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Biomedical devices	Bioprocessing
	Imaging
	Non-invasive technologies
	Tissue engineering

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

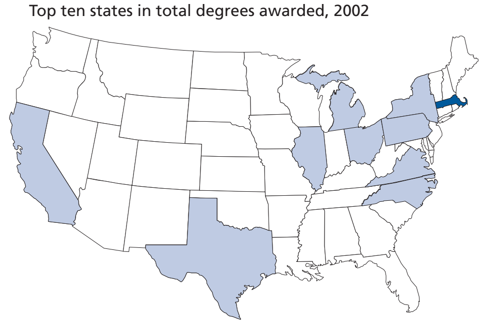
Top ten states in number of technology firms, 2003



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

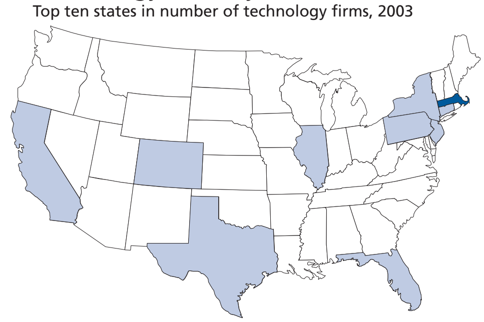
LEADING STATES

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

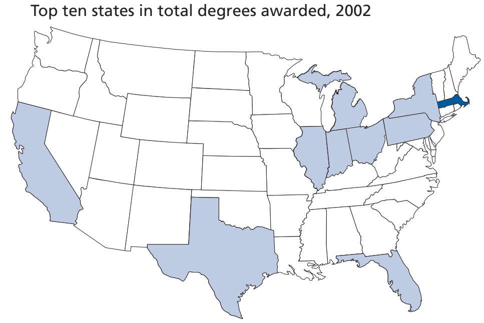
Top ten states in number of technology firms, 2003



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

Talent Generation

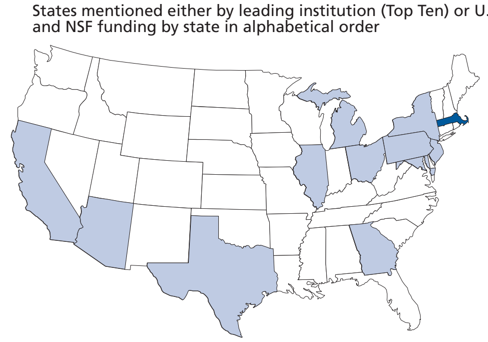
Top ten states in total degrees awarded, 2002



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.

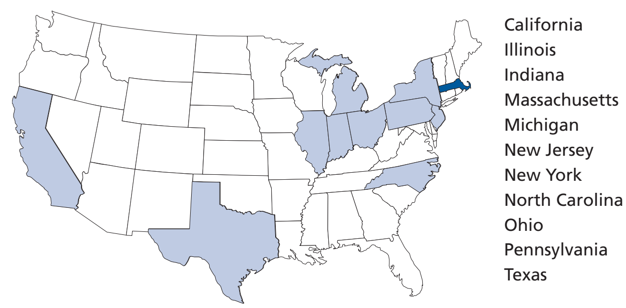
KEY INDUSTRY CLUSTERS:	EXAMPLES OF TECHNOLOGY ACTIVITIES:
Advanced materials	Polymer templating for nanofabrication Nanomagnetics
Computer and communications hardware	Nano contamination Nanoelectronics

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.

Mass Insight
CORPORATION

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