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Maine's Technology Sectors and Clusters: Status and Strategy, 2008

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Summary

The concept of "clusters" has been a key idea in economic development in Maine and other states for more than a decade. In 2002, the Maine Science & Technology Foundation released a study of the cluster characteristics of the seven technology sectors which were designated as the focus of attention for Maine's research and development support programs. In 2006, the Brookings Institution's report for Grow Smart Maine again identified clusters as a key to economic development and Harvard Business School professor Michael Porter presented the results of preliminary cluster assessment of the Maine economy.

This study is a step towards implementing the Brookings Institution's recommendations for an aggressive effort to build and expand clusters. It updates and expands the 2002 MSTF cluster report and also builds upon the work of Porter and others to identify distinctive specializations in Maine's economy by focusing in much greater detail on the knowledge, skills, networks, and entrepreneurial activities in Maine that make up clusters.

> Maine's Seven Technology Sectors
>
> Biotechnology
> Composites & Advanced Materials
> Environmental Technologies
> Forest Products & Agriculture
> Information Technology
> Marine Technology & Aquaculture
> Precision Manufacturing

The study was funded by the Maine Technology Institute and Office of Innovation of the Maine Department of Economic and Community Development. It was overseen by MTI and the Office of Innovation of the Department of Economic and Community Development. This study was conducted by the Maine Center for Business and Economic Research (MCBER) at the University of Southern Maine, which also conducted the 2002 study. The Technology Partnership Practice of the Battelle Institute, Planning Decisions, Inc., and PolicyOne Research, Inc., were partners with MCBER in conducting the study.

This summary first reviews the essential elements needed for clusters to form. The emphasis is on the knowledge and skills within a region as the foundation of clusters, so the study then examines in detail what is distinctive about research, knowledge generation, and scientific and technical education in Maine. Each of the seven technology sectors identified by the Legislature is examined in detail based on the most recent research about those sectors and on an extensive series of interviews conducted by the project team. Based on this analysis, 16 clusters are identified at various stages of evolution and other activities that might one day form clusters are identified. Recommendations for actions addressing research and development funding, ways to catalyze the development of clusters, and the need to expand the human resources needed for cluster development are presented.

1. The Concept of Clusters

The term "cluster" is so widely used that the term has become very difficult to define. Political leaders, economists, geographers, and economic development specialists are all still struggling with the concept of clusters. The ideas underlying clusters are intuitively attractive, and there is much evidence in many places that clusters do exist. The essential idea that clusters define an important element of regional economic success is largely undisputed, and much has been learned about clusters from the experience in the U.S., Europe, and elsewhere. These include:

- Industrial sectors are defined by their products. Clusters are defined by knowledge generation and knowledge spillovers, the transmission of information among the elements of the cluster. *Clusters are thus defined not by what products are made, but the knowledge and skills that reside or are developed within a region.*

- Geography is important but the exact borders of the region where knowledge and skills matter are highly variable; there is no single size of region that encompasses a cluster. We do know that clusters are more likely in urban areas than rural areas because of proximity, but rural areas still have clusters.

- Innovative organizations like universities, research laboratories, and the R&D centers of private firms are critical. But it is how these organizations interact and share knowledge with one another that is critical to a cluster. These interactions occur in networks, which make the transmission of both explicit and tacit information much more likely. Explicit information is the type shared through publications, meetings, etc. Implicit knowledge is the "shop floor" knowledge communicated as employees shift jobs.

- Entrepreneurship links research and innovation to the market. Connections with organizations that spur entrepreneurship such financing, technical assistance, or specialized services (such as intellectual property protection specialists) within the region strengthen the cluster and make commercial success more likely.

- Size matters. Innovation is inherently risky. Most ideas will fail, so economic success is always easier in regions with large concentrations of research and innovation activities. Moving knowledge around also requires sufficient number of organizations and institutions (actually sufficient numbers of people) that knowledge generation and commercial success become self-sustaining. Small regions such as Maine and small clusters, which are typical in Maine, are always challenged to generate enough research, innovation, and commercial activity to spur wider development in the economy.

These conclusions lead to a simple view of a complex phenomenon. In this view clusters have four elements that relate to one another summarized in Figure A.

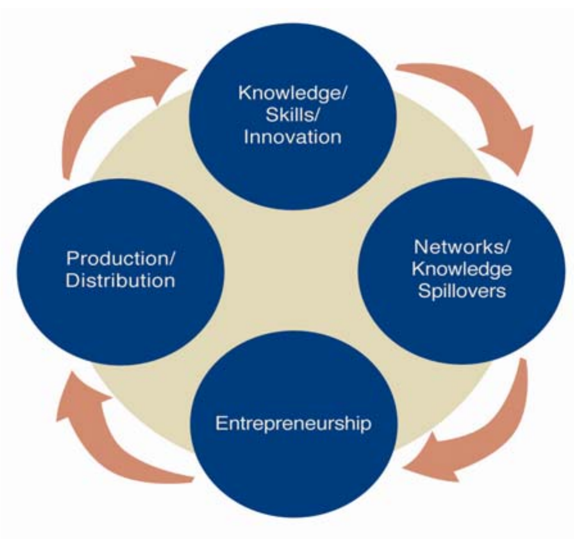


Figure A

2. The Knowledge and Skill Foundations of Clusters

Since knowledge and skills and innovation are the defining elements of clusters, the first question is: "What are Maine's distinctive knowledge and skills?" To answer this question, a detailed analysis of patents, grant funding, and peer reviewed publications was undertaken, followed by an examination of the "human capital" in Maine that is responsible for technology research and innovation.

The analysis of Maine research and development strengths was conducted by Battelle using a sophisticated text analysis tool that examined the content of over 7,300 records of patents, grants, and publications to determine which areas of research may be said to be distinct in Maine. The result identifies a number of areas of research strength which can be further grouped into the major areas of research strength (or "meta-clusters") shown in Table A.

Major Areas of Research Strength	Number of Records
Advanced Coatings, Deposition, Membranes, & Films	166
Astrophysics	224
Crop & Soil Sciences	458
Earth Sciences	78
Electronics & Semiconductors	395
Food & Dairy Sciences	193
Forestry	188
Glaciology/Ice Cores/Climatology	271
Marine Biology - Marine Animals	372
Marine Biology - Phytoplankton & Nutrients	261
Medical Sciences - Bone & Hematopoiesis	264
Medical Sciences - Cancer & Oncology	134
Medical Sciences - Cardiovascular	220
Medical Sciences - Genetics & Genomics	542
Medical Sciences - Immunology & Infectious Diseases	138
Medical Sciences - Surgery	135
Wildlife/Habitat Conservation	206
Wood, FRP, and Composites	250

Table A

Of these 19 areas of research strength, only three (astrophysics, glaciology, and earth sciences) are not areas where research is directly relevant to commercial activities in Maine. The other areas of research strength indicate:

Significant research in medical sciences, marine sciences, crop & soil sciences, and forestry/environmental sciences

Strong grant and publication levels indicate these areas provide the most extensive research base in the state as measured by this data. The volume of medical sciences research emanating from The Jackson Laboratory dwarfs the rest of the current biotechnology industry. The potential connections to Maine's industries and the translation of these areas into economic drivers for the state of Maine will require additional evolution of research in these areas as much of the current research is "basic" in nature. Additionally, while the State's research enterprises demonstrate strengths in a full spectrum of marine sciences the translation of pieces of this vast research portfolio into "aquaculture" may require significant applied research efforts and both academic as well as private sector entrepreneurs.

Research in wood/fiber-related composites is robust

The cluster analysis highlighted Wood, (Fiber Reinforced Polymer), and Composites as a research niche within the State. This (and, potentially, in combination with identified research strengths in Forestry and Advanced Coatings, Deposition, Membranes, & Films) provides the State with a uniquely "Maine" avenue to pursue advanced materials development that is the foundation for the composites and advanced materials sector

Innovation in IT and manufacturing clusters is dominated by industry efforts/patents

While some academic research efforts exist, through the patent and cluster analysis it is apparent that much, if not most, of the innovation that occurs in the IT, computer, and manufacturing clusters is led by industry efforts.

Maine has distinctive research capacities in a number of fields directly related to its cluster strengths.

In addition to the wide ranging research strengths demonstrated by the outputs of research, Maine is home to a number of research institutions with distinctive capacities on which clusters can be built, especially in biomedical and biological research, composites and advanced materials, chemical engineering, forest management, and geographic information systems.

3. The Human Resources Foundations of Clusters

Research and innovation are done by people, and a key question is whether Maine is producing the workforce needed to sustain and expand a technologically innovative economy. There are questions about the distribution of the appropriate skills in the existing workforce and also about the education and training of new entrants. To address these questions, an occupational analysis of the STEM (science, technology, engineering, and mathematics) workforce is undertaken along with an assessment of graduates in these fields from Maine's institutions of higher education. *These analyses showed that Maine has a substantially smaller proportion of its workforce in STEM occupations than the U.S. as a whole and, despite some growth, is not producing numbers of technically trained workers to create a competitive advantage for Maine.* Specifically:

- The proportion of Maine's workforce in STEM occupations is 30-40% less than the national average, and Maine lost many jobs in these fields between 2000 and 2006. The strongest area for Maine and the one showing significant growth is in the physical and biological sciences. The biological and environmental sciences account for much of this strength in Maine.

- Maine has seen a slight growth (7.5%) in higher education degrees with STEM majors/concentrations over 1996-2006. All of the growth was accounted for by women, primarily studying in the biological/biomedical fields and in natural resources and conservation related fields. Computer related fields have also shown growth; these fields are still primarily made up of men.

- The University of Maine is by far the largest producer of STEM related degrees in Maine. The private liberal arts colleges of Colby, Bates, and Bowdoin are second, although most of the graduates of these institutions leave Maine.

- STEM degrees are disproportionately concentrated at the bachelors level in Maine compared with the U.S. Maine is disproportionately below the U.S. in the production of graduate degrees in STEM fields.

The analysis of research strengths and the technical workforce shows definite patterns of knowledge and skills that underlie clusters in Maine. *There are clearly distinct elements of strength in the biological and biomedical sciences and in fields related to the environment and natural resources.* Emerging technological research areas such as composites also appear. However, many key knowledge areas do not show up in this data. Aquaculture related research does not appear as a distinct field because it is subsumed with the major research area of marine biology and aquatic sciences. It should also be noted that there is also an enormous volume of what cluster researchers call "tacit" knowledge, the knowledge that is found on the shop floor that is not measured by this data.

4. Clusters and the Technology Sectors

The seven technology sectors defined by the Legislature broadly define the areas of the Maine economy where technological innovation is particularly critical to commercial success, but the sectors are very diverse in size and characteristics. The sectors have to be examined in detail to determine what clusters may be present within, or between, the sectors. Fortunately a number of studies of these sectors have been completed over the past few years with funding from the MTI Cluster Enhancement Program. The results of these studies were supplemented by extensive interviews with individuals in research organizations, private firms, government, and higher education conducted for this study.

Clusters do not come fully formed. They evolve as networks evolve from concentrations of research and innovation within a region. This process of evolution results in three stages:

- *Potential Clusters* have high level of knowledge and skills in Maine, but there are weak networks and/or low-level commercial activities based on that knowledge and skills.

- *Emerging Clusters* show some strength on all four elements of clusters, but are relatively small or new.

- *Sustainable Clusters* show at least some strength on all four cluster characteristics, though there may exist unevenness in the strengths. The clusters have been in existence long enough to demonstrate consistent levels of innovation over a period of time.

BIOTECHNOLOGY

Maine has developed distinct knowledge and skills bases in genetics/genomics and the development of commercially successful products in the diagnostics markets based on knowledge of antibodies and related biochemistry/biology fields. The large and growing volume of research indicates potential clusters which may emerge in the future, while the diagnostics/antibodies industry represents a current emerging cluster. However, biotechnology clusters are very small scale in Maine.

The keys to growing and strengthening these clusters include: continuing to support expansion of research and development in the biomedical sciences; expanding the workforce, particularly those with graduate training; supporting creation of new biotech firms; and linking to networks and alliances with major biotech firms for financing and product development.

COMPOSITES & ADVANCED MATERIALS

Composites & advanced materials is the technology sector which, as a whole, best approximates a sustainable cluster in the sense developed in this study. The sector and its industries are grounded in a clearly defined set of knowledge and skills, which are strongly identified with Maine. Both formal and informal networks have arisen to develop and widely diffuse the key knowledge and skills. There is strong evidence of entrepreneurship in the historic boat building industry, which has adapted to new market conditions, and in new companies looking to find new markets for products made from composite materials. Finally, there is a substantial critical mass of commercially successful firms that are selling in global markets products based on the knowledge and skills centered in Maine.

ENVIRONMENTAL TECHNOLOGIES

Environmental technologies is a highly diverse sector from which has emerged a clear set of directions in the fields of environmental services and engineering. Maine has a definable advantage in the knowledge and skills in this area, with a diversifying set of activities to meet growing markets. Maine's own commitment to a high quality environment serves as a spur to innovation in this field, which may permit national and global markets to be served. The environmental services subsector is the one part of this diverse sector that has the characteristics of a sustainable cluster.

Other parts of the sector are not of sufficient size or organization to characterize them as clusters. The environmental products subsector is difficult to measure, and is still somewhat small. Renewable energy has had up and down cycles in Maine, and is very likely poised for a significant up cycle over the next decade. There is growth potential in both these subsectors that may very well yield clusters in Maine within the next decade. The worldwide demand for certified "green" products is already growing rapidly, as is the role that Maine will play in renewable energy production using technologies such as wind.

FOREST PRODUCTS & AGRICULTURE

Forest products and agriculture are each grounded in a very solid base of knowledge and skills backed by extensive research facilities centered at the University of Maine. Since these sectors have been embedded in the Maine economy for so long and have achieved significant scale of operations, both forest products and agriculture contain a number of clusters that have shown they are sustainable over time.

Though still facing mature and highly competitive markets, there are opportunities for innovation opening in each subsector which may provide new chances for growth. Some of these opportunities are variations on traditional product lines, such as the increasing market for specialized food products for niche markets, such as gourmet foods. Others are at the cutting edge of biotechnology, as in bio-fuels and bio-plastics, which will require significant growth in Maine's research capacities.

INFORMATION TECHNOLOGY

Information technologies and the knowledge and skills associated with them are so widely diffused in the economy that one must look for more defined areas of specialization in order to identify potential clusters of competitive advantage. Maine has developed a specialization in geospatial technologies, which is an emerging cluster. In addition, there is evidence that technology development in new media, bioinformatics, and in the application of IT to measure and control technologies are all potential clusters. Future growth in IT in Maine is likely to depend on identifying and effectively filling a variety of niche application development for specialized users. The markets for individual niches may be small, but the overall potential is large.

A solid base of research and education in computer and related technologies exists in Maine, but it does not emerge as research strength in the analysis of research outputs. The workforce is the key to development of this sector, because of the relatively low technological barriers to entry. It does not appear that Maine's higher education institutions are producing graduates near industry demand, and that growth is heavily dependent on recruiting a workforce from out of state.

MARINE TECHNOLOGY & AQUACULTURE

Aquaculture exhibits the characteristics of a sustainable cluster. The markers for its products are strong and could grow significantly given the world's demand for seafood and the severe pressures on capture fisheries. It is a technically complex industry that still faces a number of challenges in mimicking the functions of natural ecosystems to grow and sustain organisms, but a robust research and skills base exists in Maine to meet these challenges.

Marine research is strong in Maine, but commercial technology developments emerging from that research have lagged behind other states. The strength of the research foundation in Maine, together with growth in demand for technologies related to ocean observing and measurement over the next decades, means that clusters may yet emerge from this sector.

PRECISION MANUFACTURING

The precision manufacturing sector comprises two distinct subsectors: metal products and electronics. Each has a small number of very large world-scale firms and a much larger number of smaller companies serving a variety of customers, primarily outside Maine. The electronics sector shows high rates of innovation as measured by patents. Innovation capacity rests primarily within the private sector, though higher education institutions provide some support. Knowledge spillovers and networks within the subsectors appear to be relatively low.

The large firms in each subsector have weak supplier/customer relationships within Maine. These are somewhat stronger for smaller firms, but still weak overall. While the subsectors may be considered sustainable clusters, the links within Maine are a noticeable weakness as a cluster. The economic development potential of this sector for Maine may be improved if this sector can develop closer relationships with other clusters as, for example, in measuring and controlling technologies.

5. Technology Clusters in Maine Today

The result of this analysis is the identification of 16 clusters of economic activity, each defined by a distinct set of knowledge and skills. Eight of these are sustainable clusters, five are potential clusters, and three are emerging clusters. Some of the clusters are coincident with the technology sectors. This is the case with Composites and Advanced Materials, which rests on a set of skills in the development of New Materials combining dissimilar materials. It is also the case with Aquaculture (though not marine technology).

Other clusters cannot be categorized within single sectors. Bioinformatics and measuring/controlling devices combine Information Technology with knowledge from other fields. Chemistry and Chemical Engineering contributes to current forest products and may contribute to major new products such as bio-fuels which might be considered Biotechnology or Environmental Products. Another overlapping cluster is "shaping and fabricating" which represents a set of knowledge and skills that is at the core of Precision Manufacturing, but is also critical to the commercial development of Composites and Advanced Materials, as well as the wood products industry (though for simplicity, this link is not shown).

Figure B maps the clusters against the sectors. It also shows the different stages of clusters and also shows several clusters which overlap one or more sectors. Most of these overlapping clusters are potential clusters, which represent potentially important areas of opportunity.

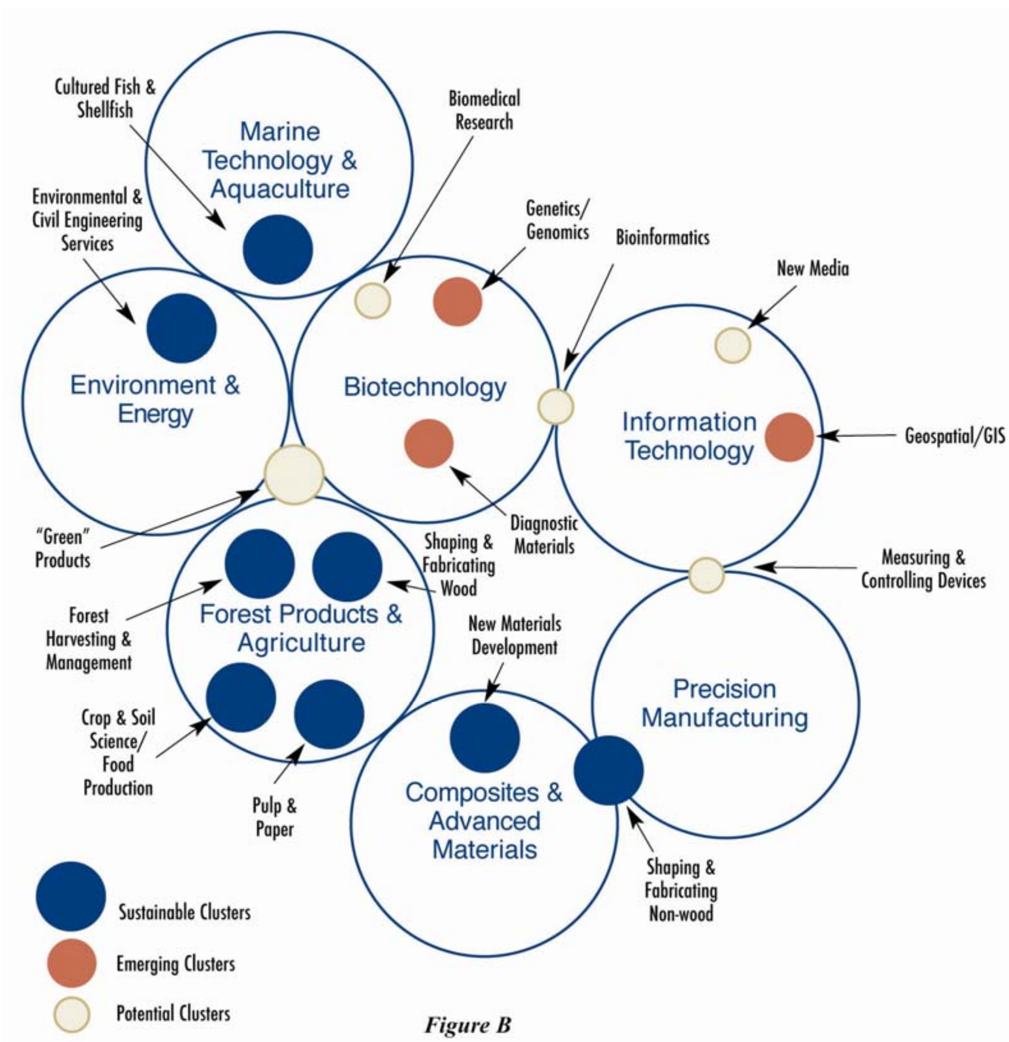


Figure B

If clusters are based on knowledge and skills, their ultimate importance to the economy depends on how these are translated into commercial products and services. In table B, each of the clusters is associated with current and potential economic activity in Maine. The identification of potential economic activity is based on information gathered in the interviews and surveys of the industries that are associated with each of the clusters. Both current and potential activities comprise a wide range of contributions to the Maine economy.

Assessment of recent economic trends in the industries associated with each of the seven sectors and of the potential economic activity towards which innovation is occurring shows that economic performance as measured by employment has not been strong except in Biotechnology, Environmental Services, and Food Products. Output and profitability may have grown in various industries within the clusters, but economic growth has been weak in key industries like Forest Products, Electronics, and Information Technologies.

At the same time, opportunities are identified in a variety of new and expanded markets which, if exploited could yield significant economic impacts. Examples include the possible markets for certified "green" products, the use of forest and agricultural inputs for fuel or plastics production, a wide array of new products for human health, and expanded applications of composite materials.

	Knowledge/Skills	Current Economic Activity	Economic Activity
Potential Clusters	Biomedical research	Improved medical treatments	Therapeutic products
	Bioinformatics	Informational analysis products and services for genetic research	Expanded research activities
	Measuring and controlling devices	Diverse electronic and other products	Integrated software/hardware approaches to measuring and controlling
	"New Media"	Diverse services for a variety of industries	Same
	Creating "green products"	Diverse	Diverse
Emerging Clusters	Genetics/genomics	Biomedical research	Same
		Products serving biomedical research	Same
	Antibodies and diagnostic materials/processes	Diagnostic materials	Same
	Geospatial analysis/GIS	Diverse	Same
Sustainable Clusters	Developing new materials by combination of dissimilar materials or finding new applications for existing materials	Boat building, construction materials, piping, fluid control and filtering systems	Renewable energy equipment, military and transportation equipment
	Chemistry and chemical engineering	Pulp and paper, other chemicals	Wood-based fuels, plastics and other products
	Marine biology/oceanography/ husbandry related to aquaculture	Cultured fish and shellfish	Same
	Forest harvesting and management	Pulp and paper, lumber and wood products	"Sustainable Forestry" certified products
	Design, shaping, coating and fabricating materials of wood, metal, silicon, plastics, etc.	Pulp and paper, lumber and wood products, metal products electronic products	Same
	Crop and soil sciences	Commodity and specialty food products	Oil-replacing products including plastics
	Agriculture and food production		
	Environmental sciences, engineering, civil engineering	Environmental and civil engineering services	Same

Table B

Not all of the economic activity associated with the technology sectors can be said to be in clusters at this time. Marine technology, environmental products, and many software products are examples of economic activities which are present in Maine but with which it was not possible to associate cluster characteristic. These industries lacked either sufficient definition or networks, or both.

Designation as a cluster does not imply that all clusters are equally strong in each of the four essential components. Table C shows the clusters as defined by knowledge and skills and a subjective assessment of the strength in each cluster of the other three elements. A score of 4 or 5 indicates a strong element; a score of 1 or 2, a weak element; and 3, a middle point. The color coding matches the scoring except that a cross-hatched box indicates the dominant activity in that cluster is strong, but there are some elements of the commercial activity associated with that cluster that are weaker than the score implies. Again, these are judgments based on the information collected for this study.

	Knowledge/Skills	Networks/ Knowledge Spillovers	Entrepreneurship	Production/ Distribution
Potential Clusters	Biomedical research	5	2	1
	Bioinformatics	1	1	1
	Measuring and controlling devices	2	4	4
	"New Media"	3	4	2
	Creating "green products"	1	3	2
Emerging Clusters	Genetics/genomics	4	2	1
	Antibodies and diagnostic materials/processes	4	4	5
	Geospatial analysis/GIS	4	4	4
Sustainable Clusters	Developing new materials by combination of dissimilar materials or finding new applications for existing materials	5	5	5
	Chemistry and chemical engineering	5	5	5
	Marine biology/oceanography/ husbandry related to aquaculture	5	5	5
	Forest harvesting and management	5	3	5
	Design, shaping, coating and composing materials of wood	5	2	5
	Design, shaping, coating and composing materials of metal, silicon, plastics, etc.	2	3	5
	Crop and soil sciences	5	4	5
	Agriculture and food production	5	4	5
	Environmental sciences, engineering, civil engineering	4	4	5
Key	Weakness	4 - 5 Strong Element		
	Moderate Strength	3 Middle Point		
	Strength	1 - 2 Weak Element		
	Mixed Strength and Weakness			

Table C

6. Recommendations

It is clear from our analysis of clusters that they are complex and multifaceted. Clusters that can sustainably contribute to economic growth and prosperity in a region require the actions of many different types of people and organizations, sometimes in cooperation with one another and sometimes in competition. Government and public policy must play a number of different roles simultaneously, which puts great demands on public institutions particularly at a time of resource scarcity.

Maine is fortunate in that the organizational and programmatic infrastructure needed to foster cluster development is largely already in place, thanks to the investments made in such organizations as the Maine Technology Institute, the Office of Innovation, and Maine Economic Improvement Fund, and other elements of the research and development strategy that have been pursued now for more than a decade. The future tasks consist therefore of continuing and expanding what has been working and making adjustments in existing programs to take advantage of the opportunities identified here rather than having to build entirely new efforts from scratch. Four key elements of strategy need to be followed:

- Feed the R&D Pipeline
- Catalyze Clusters
- Put a Priority on People
- Continue to Fund Innovation that Contributes to Clusters

Feed the R&D Pipeline

Maine has made great strides in expanding research and development, but the scale of R&D in Maine remains small by national and global standards. Other states are attempting to do the same things that Maine is, and with vastly greater resources. For example, states, like California, Massachusetts, and North Carolina, have already committed billions of dollars of their own resources to spur biotechnology research. Given the pace of technological change, it is likely that a significant part of the economic stimulus to Maine a decade from now will come from technological innovation that is just now being envisioned. For all these reasons, research and development support must continue at a high level.

Catalyze the Emergence and Growth of Clusters

The Maine Technology Institute, with its cluster enhancement program, has the opportunity to take specific actions beyond the support of R&D activities. In seeking proposals to use cluster enhancement funds, MTI should give preference to projects that address one or more of the following six broad strategies. Each of the strategies can benefit each cluster, but the examples described below indicate clusters where the strategy may be particularly important.

- **Develop services.** Most attention is paid to product development, but clusters rely on networks of services that diffuse knowledge and enhance competitiveness. Examples include services that link biotech firms with researchers and pharmaceutical manufacturers, assistance to firms wishing to meet or exceed environmental quality standards, and improving the competitiveness of manufactured products by improving logistical and value added services.

- **Build tech networks.** Technology networks are essential to moving information, knowledge, and skills within a region and thus to the formation and growth of clusters.

The development of trade associations has been undertaken in recent years using cluster enhancement funds, with some notable successes. This should be extended to activities such as annual conferences and forums that regularly provide opportunities to exchange research and new knowledge among all the members of a cluster. Biomedical research, geospatial information technologies, environmental services, and composites are examples that could benefit from expanded and enhanced technology networks.

- **Decrease distance.** Despite many efforts to make connections, Maine is still a large state with much larger distances between key cluster components than are found in many urban areas where clusters flourish. New technologies, such as virtual presence and the use of new media technologies like iPods, have the potential to decrease distance. The Graduate School of Biomedical Sciences is an example of a networked institution which could benefit from such technologies.

- **Make connections outside of Maine.** Cluster development in Maine may depend on making better connections with clusters outside Maine. Connecting Maine clusters to customers, suppliers, and researchers outside Maine may spur growth within Maine that would not otherwise occur or would not occur until Maine clusters were substantially larger. Biotechnology and marine instrumentation and equipment are both examples of clusters which are much larger in New England, particularly Massachusetts, than in Maine, and offer opportunities for expanded networks for Maine organizations.

- **Plan infrastructure development.** Through bond issues and other support, Maine has greatly expanded support for the physical infrastructure of research and development. Such support is essential, but it has also been somewhat episodic. Long-term capital plans for research facilities could help develop a coordinated strategic perspective and assure a long-term perspective is maintained.

- **Address weaknesses.** Clusters at all levels of development have weaknesses that need to be addressed. These weaknesses include limited connections to inputs and customers within Maine (precision manufacturing), as well as the need to expand the range of commercial products available from research areas like biomedical and commodity agriculture and forest products.

Put a Priority on People

Three major workforce issues are identified which must be addressed for successful cluster development:

1. The output of technically trained people in Maine is often adequate at the associate's and bachelor's degree levels, but inadequate at the graduate level. This will require educational institutions, particularly in higher education, to expand the number of students interested in pursuing advanced education in STEM fields and, where appropriate, the degree programs available. The University of Maine System, Community College System, Maine Maritime Academy, and the Department of Education each have responsibilities to address these needs. Reinvigorating the Maine Economic Improvement Fund is also a desirable action.

2. Enhance and expand two-way knowledge and skills development between industry and educational institutions. The supply of a technically competent workforce in support of technological innovation is primarily a function of educational and training institutions, particularly in higher education. But the innovation that drives changes emerges from both

the laboratory and the shop floor. Educational institutions and training programs usually have some form of industry advisory groups, while private firms offer internship or co-operative education opportunities. These arrangements should be reviewed by all parties to make sure that they effectively incorporate and spur innovation.

3. Since Maine's levels of research and workforce are likely to remain small for some time, firms in almost every technical field must recruit most of their specialized work force from out of state. Maine's quality of place will be a key to attracting critical personnel. The work of the Governor's Quality of Place Council addresses these issues and should be considered an important part of Maine's R&D and cluster development efforts.

4. A number of clusters are facing severe work force shortages caused by an aging workforce and a lack of younger people willing to move in production type occupations. This is particularly the case with those clusters centered around traditional manufacturing industries. Collaborations among private sector firms, K-12 schools, and the community colleges have formed to address this issue in specific locations and industries, but need to be expanded.

Funding Innovation that Contributes to Clusters

MTI has a lead responsibility for state assistance to research and development activities; and its programs have been shown to be effective at achieving the purposes for which they were established. Two modifications to the grant making process for the Seed Grant and Development Award programs would better link these programs to cluster development strategies without fundamentally altering these very successful programs.

One change would be to require applicants for assistance under these programs to identify the knowledge and skills that would be enhanced by the proposed project. Applicants might also be asked how the project would enhance networking or strengthening other cluster characteristics. It is important that these NOT be the only criteria used for awards under Seed Grants and Development Awards, which should continue to fund R&D that is not, or may never be, part of a cluster, but may still lead to commercially viable products and services.

The second change is an administrative change in which proposals and awards are to be identified in part on the basis of the knowledge and skills from which a grant proposal originates, rather than the product category a proposal is aimed at. This will help develop a better understanding of key knowledge and skills, identify emerging and growing areas of research, and help understand the role of R&D support in cluster development.

Finally, it is important that MTI and DECD continue their evaluation of R&D, MTI programs, and, from time to time, the status of clusters.

Maine's transformation into a regional economy that is increasingly driven by technological innovation originating within the state is well underway. The report provides evidence of firm foundations in research, growing internal networks that transmit knowledge and skills within Maine, and increased commercial success. Yet, significant weaknesses in workforce and the market for key products remain. There is real potential for growth in many key markets, even in old-line economic activities like forest products and agriculture. However, creating and seizing opportunities will still be a long road.

Above all, Maine is still too small for the global stage on which the future of the technology based economy is being decided. Other regions in the U.S. and elsewhere see the same opportunities outlined in this report, and are investing substantially more than is Maine in enhancing their knowledge and skills and creating their technical and scientific workforce. The very real success that Maine has had to date is still a prelude to the success it must sustain into the future if technological innovation is to become a cornerstone of Maine's economy and way of life.

1. Introduction: Transforming the Maine Economy

It is no secret that the Maine economy faces some real challenges. For two centuries, we have made our living on the basis of our woods, lands, waters, and on the low-cost skilled labor upon which shoe and textile manufacturing depended. The economic activity that those resources sustained built Maine, but those resources have become greatly diminished in their ability to sustain a growing and prosperous economy. The big question is "What's next?"

For the past decade, Maine has chosen to answer that question by investing a significant share of public resources (well over $300 million, in fact) to transforming Maine into a place where science and innovation can transform the Maine economy in the same way that it is happening in the national and global economies. The emphasis has been on supporting technological innovation through research and development. The desired outcome is an economy where continuous innovation occurring within Maine drives the creation of a steady stream of new products/services into global markets.

An important idea underlying this approach has been the concept of "clusters" of economic activity. The idea of clusters stretches back more than a century in economics, but received an important update and expansion in the early 1990s by Michael Porter at the Harvard Business School (Porter 1990). More recently, a major study of the Maine economy by the Brookings Institution recommended cluster development as a central focus of development efforts in Maine (Brookings Institution Metropolitan Policy Program 2006). As that report put it,

> "…[N]ew ideas and innovation are game-changers—the key to innovation…. However, the small size and sometimes embryonic nature of many Maine clusters clearly limits their present vitality".

The recommendations of the Brookings Institution were further developed and supported by the Governor's Council on Jobs, Innovation, and Growth in its own report (Council on Jobs Innovation and the Economy 2007).

In fact, Maine has been focused on cluster development for quite some time, dating back to the mid-1990s when efforts to ramp up support for innovation and R&D began. It was intended from the beginning that formation of clusters would be an important goal. The Maine Technology Institute, the lead agency for implementing state R&D funding policy, has had a "cluster enhancement program" from the beginning. In 2002, the University of Southern Maine Center for Business and Economic Research completed a project for the Maine Science and Technology Foundation that undertook to better define and assess the status of clusters in the technology economy as defined by the Legislature (Maine Center for Business and Economic Research 2002).

This report is a follow up and expansion on the 2002 report. Subsequent to that study, there have been several important discussions of clusters in Maine. The Brookings report (Brookings Institution Metropolitan Policy Program 2006) makes much of the need to strengthen Maine's clusters without providing a great deal of specificity about what those clusters are beyond the Legislature's definition of the technology sectors. Similar themes echoed in the Governor's Council on Jobs, Innovation, and the Economy's report in support of substantial additional funding for R&D. (Council on Jobs Innovation and the Economy 2007) A detailed data analysis of Maine by Michael Porter of the Harvard Business School of Maine clusters was undertaken as part of a national study of clusters undertaken by the Institute for Strategy and Competitiveness using a detailed analysis of industrial employment and wage data. (Porter 2006)

These recent discussions of clusters in Maine point to the importance of clusters as an organizing concept, but either discuss clusters in a general way or use industry-based data that provide only a partial picture of what clusters might be found in Maine. This study builds on these earlier efforts by focusing on the foundations of clusters and how these shape a much more detailed understanding of clusters that is the necessary precursor to effective policy.

This study has been conducted for the Office of Innovation of the Maine Department of Economic and Community Development and the Maine Technology Institute, who jointly funded the research. Our goals have been 1) to assess progress in establishing innovative clusters of economic activity related to Maine's R&D programs and 2) to consider ways in which the evolution of clusters in Maine can inform future state efforts to support R&D and enhance clusters.

This study is part of an ongoing series of efforts to monitor and evaluate the outcomes of the Maine R&D support programs in order to continuously improve them. Other parts of these efforts include the regular reviews of Maine's Research and Development programs, the most recent of which covered progress in 2006 (Policy One Research Inc and RTI International 2007). The Maine Technology Institute also conducts regular evaluation of its grant programs in cooperation with the Maine Center for Business and Economic Research at USM. The most recent report of that evaluation covers the period from 2002-2006 (Center for Business and Economic Research 2007). Those reports should be consulted for detailed information on the grant programs and other elements of Maine's R&D support efforts. This report steps back from those details and examines what is happening overall in the areas where Maine policy has been directed.

1.1 An Introduction to the Concept of "Clusters"

The concept of "cluster" is simple to state, but rests on a very complex system of dynamic relationships that is very difficult to define and measure. At its most basic level, a cluster is a form of relationships of economic activity within a region. The interplay of public, private, and non-profit institutions within the region creates conditions of enhanced competitiveness so that private-sector firms profit from being located within the region and the region gains sustainable prosperity through continuing success of the firms. Put simply, business success depends on being in a specific region and regional success depends on those businesses.

This definitional equating of regional and business success defines the essential characteristics of a cluster, but begs the basic question: What is it about the region that makes this mutual success possible? This leads to our essential argument in this report: It is the knowledge and skills of researchers, technicians, fabricators, designers, scientists, and entrepreneurs and their supporting systems upon which clusters rest. ***Clusters are defined by what we know how to do, or learn how to do, not by what we make.*** This perspective cuts to the heart of what makes a region sustainably competitive in a technologically innovative economy and has a number of advantages when thinking about how best to support clusters.

In making this argument, we alter the perspective on clusters taken in the 2002 report for Maine Science and Technology Foundation. That study focused on defining and measuring those characteristics associated with cluster status as they applied to the seven sectors that the Legislature defined for programs to support research and development. We find it necessary to draw a sharp

Technology Sectors Defined by Legislature

1. Biotechnology
2. Composites and Advanced Materials
3. Environment and Energy
4. Forest Products and Agriculture
5. Information Technology
6. Marine Technology and Aquaculture

distinction between aggregations of economic activity and clusters in order to better understand what roles clusters play in Maine. The sectors defined by the Legislature may be clusters or may contain within them clusters or the possibility of clusters. We also recognize that clusters evolve through several stages and policy must respect this evolutionary process.

This perspective on knowledge and skills is made clear because much has changed over those years to build capacity and sharpen the focus of activity. This perspective also arises from research on clusters, which has grown dramatically over the last few years. To examine its applicability to Maine, we proceed through four steps:

1. First, we review the recent literature on clusters, which has emphasized the concept of "knowledge spillovers" as the glue that holds the institutions within a cluster together. Research on clusters throughout North American and Europe suggests that the knowledge/skills basis of clusters is key to their success.

2. Using data on the most widely recognized elements of research activity, we explore the output of Maine's R&D enterprise to identify "knowledge clusters" that are distinctive within Maine. These are major components of the foundation upon which commercially successful clusters are built.

3. It is people who develop and carry the knowledge and skills, so we next examine the changing size and dimensions of Maine's workforce in what has become known as the STEM (for science, technology, engineering, and mathematics) workforce. We look at Maine from an occupational perspective and also examine recent trends in higher education to see whether Maine is generating its own supply of technically skilled workers.

4. Each of the seven sectors is examined in detail. A number of interviews with key people in various organizations (public, private, and non-profit) across the seven sectors were conducted. The study also benefited from being able to incorporate a much larger body of recent studies on each sector, many of them funded by MTI through the cluster enhancement program. An examination of economic performance in the major components of each sector is also undertaken.

Our analysis has shown that many of the key elements that define clusters have strengthened over the past six years, and it is now possible to more accurately identify certain types of clusters. Some of these are what we call ***sustainable clusters***; they have sufficient knowledge/skills based foundations within Maine, a relatively dense and functioning network of institutions, and sufficient commercial scale over enough time that they can be so characterized. Examples include forest products & agriculture, composites & advanced materials, and aquaculture.

Others are still in an evolutionary stage. ***Emerging clusters*** have a defined knowledge base within Maine and many of the other characteristics of clusters, but are relatively new so that it is not yet clear whether sufficient commercial scale or innovation over time have been or can be reached. Emerging clusters include genetics and genomics, antibodies and diagnostics, geospatial analysis, and materials shaping using metals. ***Potential clusters*** have strong research bases or emerging markets in which Maine does have knowledge/skills advantages, but many of the institutional arrangements and networks are yet lacking or the scale of activity is simply too small at this stage. Examples include biomedical research and "new media."

In our conclusions and recommendations, we point to both the real progress that has been made in Maine and the real challenges we still face. Returning to a theme from the 2002 report, we note that there continues to be a mismatch between those areas where Maine has strong clusters and the potential of market growth to propel significant economic development in the state, though recent innovations may alter this. Our recommendations focus on ways to adapt Maine's R&D programs to this new perspective on clusters, point to a series of actions to strengthen the human resource foundations, and suggest a number of ways that resources specifically targeted to cluster enhancement might be used.

1.2 An Overview of the Report

This report is divided into three broad sections. Following this introduction, the first section, comprised of Chapters 2, 3, and 4, introduces the subject of clusters and provides detailed analysis of the foundations of clusters. Chapter 2 reviews recent studies on the meaning of "clusters" in the U.S. and Europe and concludes that it is the knowledge base within a region that ultimately defines both the competitive advantage and the cluster. Chapter 3 starts with this idea, and conducts a detailed analysis of research strengths in Maine using an innovative tool for the analysis of patents, publications, and grants. Chapter 4 turns to the question of who is doing the research and innovation in Maine by examining the Science, Technology, Engineering, and Mathematics professions and educational programs in the state.

In the second section of the report (Chapters 5-11), each of the seven sectors defined by the legislature is examined in detail. The findings of recent studies are combined with the information gathered from a number of interviews of people involved in each sector to identify the strong and weak elements of each sector. Recent economic changes in the sector are examined, and each sector is analyzed on the same basis as the 2002 MSTF cluster report. Each chapter concludes by identifying the clusters that are associated with each sector.

Chapter 12 is the final section. This chapter summarizes the findings with respect to the clusters in Maine and their strengths and weaknesses. It then identifies a series of recommended actions 1) to help clusters evolve from potential to emerging and from emerging to sustainable clusters and 2) to enhance the competitiveness of sustainable clusters. It also examines key weaknesses in clusters that should be addressed.

2. Clusters: An Introduction

The question of "what is a cluster" remains at the heart of this research. This chapter reviews research on the "cluster" concept as it is has evolved in Maine and in studies of clusters around the world. The review highlights some of the key elements of clusters, but also emphasizes that the idea of clusters is imprecise and still evolving. The discussion in this chapter lays the conceptual groundwork for the analysis of Maine's technology sector and clusters that follows. Readers interested in the specifics of that analysis may wish to go to Chapter 3.

2.2 Basic Questions

At the core of the analysis of clusters is the much larger question: why are some places more sustainably prosperous than others? This question has become more and more urgent in many regions as globalization alters the sources of competitive advantage that have shaped the location of economic activity for more than a century. Where once the availability of natural resources or the cost of labor were considered the prime sources of prosperity, attention has focused more recently on the capacity to innovate new products and services to serve new markets. But this only leads to another question: why are some places able to be more innovative than others?

The short answer has been clusters: the assembly within a particular region of a set of individuals and institutions which are able to be consistently innovative in terms of generating new ideas and transforming those ideas into commercially successful products. In a cluster, commercial success is made more probable by location, and the location is made prosperous by virtue of that commercial success.

This of course leads to other questions: why do clusters form at all? What keeps them going? How can a region with little history of the kinds of highly specialized and technical knowledge underlying new products develop clusters? Maine's major efforts to spur research and development over the past decade have been one attempt to answer these questions, as has the initiation of such programs as MTI's Cluster Enhancement Program. In establishing the eligibility criteria for R&D support, the Legislature implicitly identified where it thought clusters are or should be functioning.

In fact, most of the research that has been done on clusters to date in Maine tends to equate clusters with the seven technology sectors defined by the Legislature. This includes the earlier work by the Center for Business and Economic Research (Maine Center for Business and Economic Research 2002) (Colgan and Baker 2003), but in fact the seven technology sectors are aggregations based on very inconsistent bases. Some are based on a particular input (composites or forest products), others on a particular market (environmental), and still others on the basis of a production process (precision manufacturing). These definitions all describe areas of the Maine economy where innovation is, in fact, truly critical to long term success, but for which the term "clusters" may or may not be very appropriate or helpful.

The earlier CBER report built upon the cluster literature at the time by identifying several key characteristics:

Innovation
Business functions performed within Maine
Entrepreneurship Objectives

Capital sources
Relationships
Location advantage
Market potential
Economic Performance

These criteria attempted to apply a number of characteristics of clusters that were identified in the literature at that time to the situation found in each of the sectors identified by the Legislature. Much research on clusters has been done since the earlier study particularly in the U.S., Canada, and Europe. One result of this research is that a more focused view of the elements that catalyze and shape clusters has emerged. This view draws attention to two basic questions:

- How, to what extent, and in what areas is knowledge generated within that region?

- How is that knowledge diffused within the region?

The answers that others have offered to these questions form the basis for understanding clusters in Maine.

2.3 Generating and Diffusing Regional Knowledge

Knowledge Generation

The role of knowledge generation in spurring innovation is well established and widely known. It has long been recognized that standard economic models depict incentives to innovate without really explaining how the innovation will occur or why it will occur in some places rather than others. Research on "national systems of innovation" and "learning economies" have emphasized the need to shift from a perspective on economic decisions based on "rational choice" (which is by definition based on perfect information), to one based on "learning" where acquiring knowledge and skills is the precursor task to any other economic activity. (Lundvall, Johnson et al. 2007)

Much of the research on clusters tends to use existing data sources, which are based on products rather than the underlying skills and knowledge, to assess clusters that already exist within an economy. But how does an agglomeration of activity and institutions transform into a cluster? The studies that have been done tend to focus on the changing roles of locally generated v. imported knowledge. Some have suggested that in the early stages of a cluster that local knowledge is more important (Audretsch and Feldman 1996), while others (Trippl and Todtling 2007) indicate that external knowledge is more important. There does seem to be some agreement that locally generated knowledge spillovers, especially from universities, are particularly important to small and medium sized companies and tend to typify earlier stages of cluster growth.(Feldman 1994)

But there is an underlying, and largely unresolved, paradox in discussions of knowledge. (Dorling and Schnellenbach 2006) In one view, knowledge is a public good, non-excludable in production and non-rival in consumption. Alfred Marshall spoke of the knowledge "in the air" within industrial districts, something for all to grab and make use of. In contemporary economics, this view treats knowledge as a "positive externality", that is, a beneficial byproduct of location within a region. This perspective has very specific implications for regions: if knowledge once generated is available to all, there can be no regional advantage gained from being a generator or adapter of knowledge. Marshall's "knowledge in the air" becomes "on the Internet", in which case it is essentially everywhere simultaneously.

The other view is that to be commercially useful, knowledge must be a private good. Those who produce it must have exclusive rights to it and can use it to their exclusive advantage. This is the underlying theory of intellectual property protection and the provisions for the protection of trade secrets. In his study on biotechnology, Pisano identifies the key to development of this sector as the "monetization of intellectual property".(Pisano 2006) In this perspective, a region's competitive advantage is determined by its stock of knowledge, but at the extreme there are also no knowledge spillover externalities to form the competitive basis for a cluster.

In short, if knowledge is a public good there is a basis for economic growth but no regional advantage. If it is a private good, there is regional advantage but the idea of a knowledge spillover-based cluster is impossible. Theorists have tried to work around this paradox in two ways. The first is to distinguish between explicit and tacit knowledge. Explicit knowledge is essentially knowledge that is written down. It is thus easy to communicate. Explicit knowledge may be a public good (if published) or a private good (if kept within an organization as trade secret). Tacit knowledge, on the other hand, is that which is "in people's heads". It is sometimes referred to as "craftsman's knowledge". (Gertler 2007)

In this approach, knowledge spillovers of explicit knowledge occur within the region, but may be accessible outside the region. Regional advantage may exist, at least temporarily, if communication lines are short within the region; people know "who to go to" when they have a problem, rather than searching across the entire Internet. But trade secrets also exist as sources of competitive advantage for individual firms. This distinction explains most of the findings that inter-firm relationships are less important than firm-university relationships. Moreover, local advantage is definitely enhanced by the ability to communicate tacit knowledge in inter-personal relationships that would be rare or impractical at larger distances.

Knowledge Diffusion

The process of knowledge diffusion, or "the creation of positive externalities", has been intensively studied in the last few years. Johansson provides a good framework within which to consider the different types of externalities. He distinguishes between the sources, nature, and consequences of externalities. Location externalities can come from *proximity* or *links*. (Johansson 2005)

- Proximity externalities are essentially the advantages of small geographic distance, particularly the ability to minimize transport, transaction, and communications costs.

- Link externalities are generally formalized relationships of some kind. They may be contracts for buying and selling or membership arrangements in associations. Links are called networks by some (Karlsson, Johansson et al. 2005) and have characteristics of durability and sunk costs whose creation is motivated by a need to reduce uncertainties and to further reduce (beyond any advantages conferred by proximity) transaction costs. The exact extent to which formality is required is a matter of some debate in the literature.

A good example of the study of "proximity externalities" is the body of work on mobility among workers within the dense (usually urban) labor markets characteristic of clusters. (Power and Lundmark 2004) The seminal work on this subject is Saxenian's (1994) study of the growth of the electronics and computer industry in Silicon Valley and Route 128. She found that a very high degree of mobility of workers between firms was essential to Silicon Valley's sustained success. She documents an array of formal and informal ways in which people in "the Valley" were more attached to their particular specialty than to any one company, and through a series of informal connections (for example, the famous Wagon Wheel Bar) and constant inter-firm movement, both the explicit and tacit knowledge of computers and software were rapidly spread through the region.

In contrast, in the 1980s there was almost no inter-firm mobility among workers in Massachusetts. People worked for Digital or Data General or Wang, and the culture was very hostile to cross company movement of people, or even socializing with one another. The result was the demise of the mini-computer industry in Massachusetts at the time when the computer revolution was really taking off in Silicon Valley. In more recent work, Saxenian has shown how large networks of people that span nations and continents are evolving as new paths of knowledge transmission. (Saxenian 2007)

There is also a large body of research on the formal links or networks that help knowledge to diffuse within a region. Two types of organizations and the relationships among them have received the most attention in the literature: inter-firm relationships within the region and industry-university connections.

A number of different types of links between firms have been proposed as conveying key information that can be used for competitive advantage. Information from suppliers and customers are the most frequently cited. (Porter 1990) There are also inter-firm collaborations for product development (Saxenian 1994). But the evidence on the strength of these inter-firm regional relationships is "quite mixed". "Where inter-firm collaborations do exist, it can be highly dependent upon variables such as firm size, sector, firms' past innovation record, and the level of local attachment". (Malmberg and Power 2005).

Competition among firms in the region is also cited as an important externality. Porter identifies "firm structure and rivalry" as one of the bases on his diamond model. (Porter 1990). A distinction is drawn between competition, which is a normal market condition, and rivalry, which is a more intense and sustained competitive relationship which is much more focused and more likely to affect firm behavior. (Boari 2003)

Malmberg and Power's survey of the empirical literature on clusters does find that the "strongest evidence" supports the importance of localized business-university links. They cite studies to the effect that these links are particularly important for small and medium sized firms, and that it is formal collaborations embodied in "market exchanges" between businesses and universities that are particularly critical. At the same time, they note, most of these studies focus on industries where patentable knowledge is the primary output of the relationships, which is only a subset of the larger set of knowledge creation possibilities.

Externalities are also seen by Johansson as having two different effects on aspects of business operations: *efficiency* externalities and *innovation* externalities. (Johansson 2005)

- Efficiency externalities are those which advantageously affect the price of inputs or outputs. Johansson refers to those business activities affected as *supply activities*, or those using fixed routines and inputs. They affect competitive advantage through more or less the classic mechanisms of affecting production efficiencies and costs, including the creation of economies of scale (and presumably scope).

- Innovation externalities affect *development activities,* or what would traditionally be called R&D, and which attempt to change the nature of inputs and outputs.

This distinction between efficiency externalities and development externalities points to another important element in the literature: the distinction between regional externalities that emphasize the creation and transmission of knowledge leading to innovation and those that merely improve efficient production. Clusters may be said to do both, and it is the mechanisms by which clusters act to increase and diffuse knowledge and innovation that has been a key element in the study of clusters. It is this aspect that has led to clusters also being described as the foundation for "learning regions" or "centers of innovation".

In all of these studies of knowledge diffusion there is an explicit recognition that such diffusion ("externalities") is much easier within a relatively small geographic area. But how small? Or to ask the question another way: how big does the region have to be before knowledge diffusion externalities become too costly as to be only minimally effective?

The question of geography is among the most unsettled in all of the literature on clusters. (Dorling and Schnellenbach 2006) In his original work on clusters, Porter discusses geographies as small as Omaha, NE and as large as Japan (Porter 1990). Karlsson et al. distinguish between *intra-district* externalities which function in a sub-region of a functional urban region, *intra-regional* externalities which function within the entire urban region and *inter-regional* which function between regions. (Karlsson, Johansson et al. 2005) This conceptual model is simple, but what happens if there is no "urban region" involved?

An effort to combine both theoretical and empirical approaches to the geography question is undertaken by Litzenberger and Sternberg in an assessment of clusters in Germany. (Litzenberger and Sternberg 2005) They note that the mere measurement of specialization (using such traditional tools as the location quotient) in a region is an insufficient measure of possible clusters. They use a combination of industrial stock (measured of relative employment as proportion of population) and industrial density (employment per unit of area) to identify four possible combinations of geography and industry, shown in Figure 1.

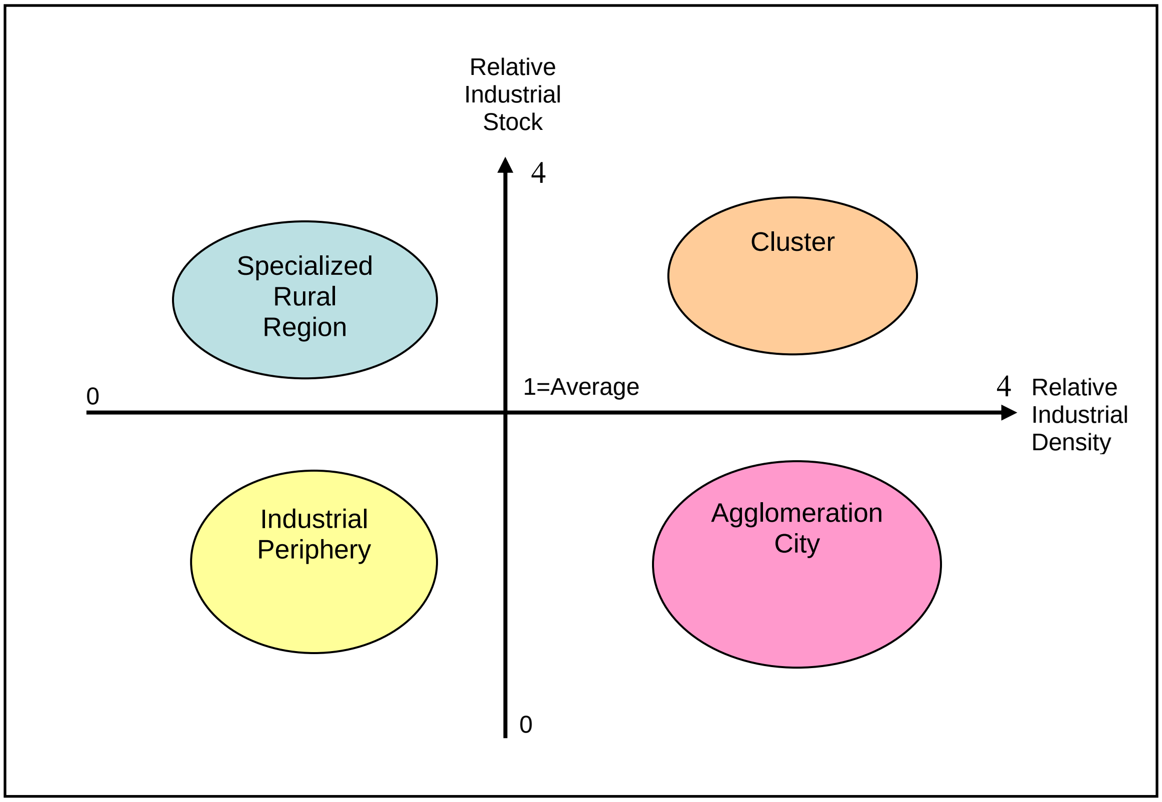


Figure 1 Geography and Industrial Definitions of Clusters

In the Litzenberger and Sternberg model a *specialized rural region* has a higher than average degree of specialization in an industry but lower than average density of employment. The *industrial periphery* is the area in the usual economic geography models of cities in which manufacturing is located between the agricultural periphery and city center. This region is typical of the dispersed manufacturing in rural areas. High density but low specialization characterizes the *city*, where dense markets characterize urban areas, at least for the local (non-traded) sectors. These give the urban region a high degree of diversity (low degree of overall specialization) in a small area.[1] Finally, the *cluster* is represented by both a high density and a high degree of specialization.

These different concepts of agglomeration can be illustrated in Maine. The Specialized Rural Region is exemplified by the mill towns and their surrounding regions such as Millinocket or Lincoln. These areas are very specialized, but they are small in overall employment. Industrial peripheries were originally manufacturing oriented, but today are more characterized as "edge cities" where there is a combination of office space and retail. The Bangor Mall region, the Belgrade Exit area of Augusta, and the Maine Mall region of Portland-South Portland-Scarborough-Westbrook. The agglomerate city is found in the cities, Portland, Augusta, Bangor, Lewiston, Auburn, etc. Each one of these represents a different mixture of agglomeration and specialization, but none represents a cluster which combines geographic proximity, specialization, and high employment density. One critical question is what is the required level of geographic proximity?

[1] The term "agglomeration economies" is frequently used with respect to clusters, but "agglomeration" is also widely used as a substitute for "urbanization" economies. As pointed out by Litzenberger and Sternberger and others, such economies focus on local market size and primarily affect the size of the non-traded sectors in the economy, where we are most interested in the economies affecting the traded sectors. For this reason "economies of co-location" seems a more accurate term.

Some empirical studies have been done to try to fix a reasonable geographic boundary, at least with respect to certain types of knowledge spillovers. One study found that universities had an effective radius of about 50 miles for increasing innovative activities (Anselin, Varga et al. 1997), while another found an effective radius of about 75 miles (Varga 2000). However, no empirical studies have found a reliable geography for the externalities associated with private R&D. In one study of an "immature technology industry", private R&D connections well beyond the borders of the region (in this case Austria) were found to be much more important than "local" connections. (Trippl and Todtling 2007)

2.4 Entrepreneurship

The emphasis on innovation in the development of clusters implies a high rate of entrepreneurship, usually in the development of new companies (though sometimes in the development of new activities within organizations instead of the creation of new organizations). There is an expectation that clusters will contain a large number of new companies as technological and knowledge innovation creates new opportunities. This characteristic incorporates into the theory of clusters the large literature on entrepreneurship, small business startups, and the issues of financing, etc.

2.5 Summary

Economists, geographers, and economic development specialists are still struggling with the concept of clusters. The ideas underlying clusters are intuitively attractive, and there is much evidence in many places that clusters do exist. The essential idea that clusters define an important element of regional economic success is largely undisputed.. But why clusters exist where they do and whether or how those experiences can be translated into other regions remains a matter of debate because there many different paths to the creation of clusters. Nonetheless, some essential threads are clear:

- Industrial sectors are defined by their products. Clusters are defined by knowledge generation and knowledge spillovers- the transmission of information among the elements of the cluster. The knowledge foundations of clusters may support many different products in many different industries. Clusters are thus defined not by what products are made, but the knowledge and skills that reside or are developed within a region and the relationships among institutions that transmit that knowledge within the region. Rather than focus on what we make, it is what we know how to make and do that is critical.

- Geography is critical to commercial success but the exact borders within which geography matters is highly variable; there is no single geography that encompasses a cluster. Clusters are more likely in urban areas than rural areas, but rural areas can have cluster characteristics.

- Innovative organizations are critical, and it is their networked inter-relationships that matter. Networks make the transmission of tacit information much more likely, and speed the transmission of explicit information by reducing search time and costs.

- Networks around university-industry links are particularly important, although in reality the concept of "university" should be extended to any organization with a research/education function. Entrepreneurship links research to the market. Inter-firm networks within the region are also important, but their role can be highly variable.

- Size matters. Innovation is inherently risky. Most ideas will fail, so economic success is always easier in regions with large concentrations of research and innovation activities. Moving knowledge around also requires sufficient number of organizations and institutions (actually sufficient numbers of people) that knowledge generation and commercial success become self-sustaining. Small regions such as Maine and small clusters, which are typical in Maine, are always challenged to generate enough research, innovation, and commercial activity to spur wider development in the economy.

These conclusions lead to a simple view of a complex phenomenon. In this view clusters have four elements that relate to one another:

- A source of knowledge, skills, and innovation. This is typically higher education institutions which combine the tasks of research and education, but also includes the non-profit research organizations, as well as businesses which can be a major source of innovation.

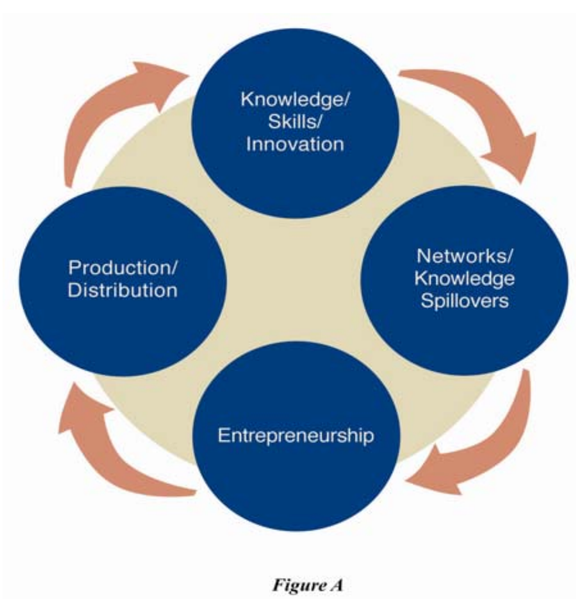
- A way to move this knowledge around within the region. This are described as knowledge spillovers, innovation networks, or other names, but they all describe the way that both formal and tacit knowledge is communicated within the region.

- Entrepreneurship to begin the process of transforming new ideas into commercially available products.

- Commercial production and distribution.

These elements can be depicted as shown in Figure 2.

Figure 2 Cluster Elements



These elements combine in different ways to form clusters. Clusters may start with a single company successfully making a product. Other companies are lured to locate nearby, an industry grows with new firms, the industry and public collaborate to enhance the research and education institutions from which additional ideas generate new products and new companies. This sequence might describe a natural resource industry like agriculture or aquaculture. Or the sequence might start in the research element; new research leads to new products and companies. This is the type of growth that described what has been happening in biotechnology, particularly in centers such as Massachusetts and California. Or a single company may give rise to several spin-off companies which transfer workers (and knowledge) among one another. This describes the growth of Maine's antibodies/diagnostics cluster.

While clusters may start at different points, they must ultimately comprise all four elements at sufficient scale and for a sufficient time that they can have a significant influence on the regional economy. They must be "propulsive" to use the term of the French economist Francois Perroux. Clusters must go through an evolutionary process during which each of these four elements is established, matures, and begins to have a direct effect on the economic success of the region. This evolutionary process can be thought of as having three stages:

- Potential Clusters

  A set of knowledge and skills is identifiable upon which a sufficient level of economic activity within the region is based. Organizations associated with the knowledge and skills (public, private, and nonprofit) are also identifiable and have at least some form of interrelationship with one another. Knowledge and skills are largely confined within the organizations and not yet widely shared among them. Institutions tend to remain separate and collaborate only on an occasional basis and for very limited purposes if at all.

- Emerging Clusters

  A set of knowledge and skills that is generating measurable economic activity in a region and which is being increasingly shared among the organizations that create and use these knowledge and skills. This sharing of knowledge across organizations is becoming more and more important to the success of the organizations both individually and collectively. Commercial success is seen as increasingly dependent on the relationships among organizations within the region. Collaboration among institutions is increasingly seen as routine and necessary for success.

- Sustainable Clusters

  A set of knowledge and skills that meets all the tests of an emerging cluster and has been shown over time to produce sustainable levels of economic activity that are driven by continuous innovation. The innovations are in large part the products of the network of organizations and people that make up the cluster. Institutional collaboration is recognized as essential for all parties.

In the succeeding chapters we look at the knowledge and skills foundations of clusters in Maine, as evidenced by an analysis of indicators of innovation (in chapter 3) and of the presence of occupations and education programs relevant to technology innovation in Maine (in chapter 4). Following this analysis we look at each of the sectors defined by the Legislature. In these chapters we look for evidence of the four characteristics of clusters discussed above and attempt to distinguish between clusters at various stages of the evolutionary process and activities which are still best defined as industries only. The concluding chapter summarizes the findings from these chapters and presents recommendations for spurring clusters in Maine.

3. Maine's Research and Innovation Strengths

Identifying the knowledge and skills foundation of a region is notoriously difficult largely because these are concepts that are very difficult to measure. One approach that is commonly used is to examine a number of quantitative measures such as Federal grants, patents, and publications in the scientific literature. Each of these provides a useful perspective on the generation of knowledge, and this chapter analyzes Maine on the basis of these useful but imperfect measures. Limitations on the data include the fact that patents are the appropriate means of intellectual property protection for some kinds of technologies, but not all. For example, software is copyrighted rather than patented. Also, publications in peer reviewed outlets are common in some industries, but rare in others.

The chapter begins by discussing each of these measures to assess what they say about research in Maine. It then takes an important step beyond the analysis of individual measures by identifying the commonalities among all of them that define the research strengths emerging within Maine using an analysis tool developed by Battelle specifically for this purpose.

Any analysis using standard data sources as patents is limited to the kind of activity that will show up on such measures. Another approach to looking at research capacity is to examine key research facilities in Maine to assess what is uniquely available in terms of technology, research personnel, and programs. Whereas the quantitative assessment examines one group of outputs from research, this approach examines capacity. An overview discussion of key capacities is provided in this chapter. Additional assessment of research is provided in the chapters on each sector.

3.1 Data Overview

To understand the research and innovation strengths of Maine, a number of unique data sets are examined to provide an analytical and quantitative assessment of the State's capabilities. Three data sets are used for this analysis including: 1) research grants abstracts from Maine researchers; 2) U.S patent abstracts from Maine inventors; and 3) abstracts for articles and papers appearing in peer-reviewed journals. While these data are gathered for the ultimate purpose of input for an analysis of which activities can be meaningfully "clustered" together, some meaningful insights can also be gained through closer examination of each of the three datasets on their own. Table 1 summarizes the overall structure of the datasets used.

Table 1 Source Detail of Maine R&I Information and Text Inputs

Type of Record	Number of Records
Research Grants	**1,514**
• *National Science Foundation*	*461*
• *National Institutes of Health*	*399*
• *U.S. Department of Agriculture*	*339*
• *U.S. Department of Defense*	*107*
• *U.S. Department of Commerce*	*95*
• *NASA*	*44*
• *U.S. Department of Interior*	*28*
• *U.S. Department of Energy*	*21*
• *U.S. Department of Transportation*	*11*
• *U.S. Environmental Protection Agency*	*9*
U.S. Patents	**1,188**
Publication Abstracts (from Thomson)	**4,609**
Grand Total	**7,311**

Sources: NSF, NIH, USDA, RAND-RaDiUS, Thomson Current Content Connect, Thomson Delphion Patent Database; Battelle Calculations

Table 2 provides distributional details of these 7,311 input records showing those companies and organizations with 20 or more records in the overall dataset.[2] With publication abstracts accounting for 63 percent of the records, it is not surprising that academic and research institutions account for the vast majority of records. The organizations included in Table 2 account for a combined 5,528 (or 76 percent) of all records in the dataset.

Table 2 Maine Organizations with 20 or More Records in Input Dataset

Organization	Records
University of Maine	2,243
Jackson Laboratory	1,115
Maine Medical Center	511
Bowdoin College	225
University of Southern Maine	190
Mt. Desert Island Biological Laboratory	161
Bigelow Laboratory for Ocean Sciences	155
Bates College	137
Colby College	128
University of New England	102
Fairchild Semiconductor Corporation	70

[2] Note, some of these organizations may have facilities in Maine, while not headquartered in Maine.

Organization	Records
Foundation for Blood Research	57
St. Joseph Hospital	48
IDEXX Laboratories, Inc.	45
National Semiconductor Corporation	45
SPX Corporation	43
Fiber Materials, Inc.	36
Maine Department of Agriculture	31
USGS	31
Eastern Maine Medical Center	26
Maine Department Marine Resources	25
MariCal, Inc.	23
Wells National Estuarine Research Reserve	21
BioDiversity Research Institute	20
Sensor Research & Development Corporation	20
United Technologies Corp./Pratt & Whitney	20

Source: Battelle Calculations

3.2 Federal Research Grants Analysis[3]

National Science Foundation (NSF) Grants

The University of Maine system accounts for just over half (234 awards; 51 percent) of the 461 NSF awards to Maine's institutions. The Bigelow Laboratory for Ocean Sciences is the second largest recipient at 48 awards.

The strengths of Maine's institutions in a broad spectrum of "environmental sciences" is shown in NSF awards in Table 3. The Division of Ocean Sciences accounts for 70 awards while the Antarctic and Arctic Sciences Sections combine to provide 66 awards. Additionally, the Divisions of Earth Sciences and Environmental Biology account for 52 additional awards. The Division of Undergraduate Education provides awards which have a strong teaching component to them.

[3] Grants included Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) to companies when this information is included in the data set.

Table 3 NSF Research Grants to Maine- NSF Division with 5 or More Awards

NSF Divisions/Offices Providing Grants	# of Maine Awards
Division of Ocean Sciences	70
Antarctic Sciences Section	41
Division of Undergraduate Education	27
Division of Earth Sciences	26
Division of Environmental Biology	26
Arctic Sciences Section	25
Division of Biological Infrastructure	25
Division of Integrative Organismal Systems	22
Division of Chemistry	21
Office of Industrial Innovation and Partnerships	18
Division of Atmospheric Sciences	13
Division of Graduate Education	13
Division of Behavioral and Cognitive Sciences	12
Division of Molecular and Cellular Biosciences	12
Division of Physics	12
Division of Information & Intelligent Systems	11
Division of Elementary, Secondary & Informal Education	10
Division of Social and Economic Sciences	9
Division of Chemical, Bioengineering, Environmental, and Transport Systems	8
Division of Civil, Mechanical and Manufacturing Innovation	8
Office of Integrative Activities	8
Office of International Science and Engineering	7
Division of Engineering Education and Centers	6
Division of Materials Research	5
Other NSF Divisions	*26*
NSF, Totals	**461**

Source: NSF Fast Lane Database; Battelle Calculations

National Institutes of Health (NIH) Grants

Of the 399 NIH grants awarded to Maine institutions, 251 (or 63 percent) were awarded to The Jackson Laboratory. The next largest number of awards was to the Mount Desert Island Biological Laboratory with 25 grants.

The largest single source of grants from within the NIH to Maine institutions is the National Center for Research Resources, a source for research infrastructure and equipment related awards (Table 4). Among the disease related institutes and centers, the largest number of awards come from the National Institutes of Diabetes, Digestive, and Kidney Diseases; Child Health and Human Development; and Heart, Lung, and Blood—each accounting for at least 35 awards.

Table 4 NIH Grants to Maine- Institutes with 5 or More Awards

NIH Institute, Center, or Division	# of Grants
National Center for Research Resources	63
National Institute of Diabetes, Digestive, and Kidney Diseases	37
National Institute of Child Health and Human Development	36
National Heart, Lung, and Blood Institute	35
National Cancer Institute	30
National Institute of General Medical Sciences	28
National Human Genome Research Institute	24
National Institute of Neurological Disorders and Stroke	20
National Eye Institute	16
National Institute of Allergy and Infectious Diseases	16
National Institute on Deafness and Other Communication Disorders	15
National Institute of Arthritis and Musculoskeletal and Skin Diseases	13
National Institute on Aging	13
National Institute of Environmental Health Sciences	12
Agency for Healthcare Research and Quality	11
National Institute of Mental Health	7
Other NIH Institutes, Centers, or Divisions	*23*
NIH, Totals	**399**

Source: NIH CRISP Database; Battelle Calculations

U.S. Department of Agriculture (USDA) Grants

Limited organizational or USDA subdivision reference data is supplied with the USDA research grants. Needless to say, the vast majority of grants (80 percent) are to the University of Maine (primarily the University of Maine or the University of Maine System Administration office).

3.3 Publication Analysis

Within the publications examined for this analysis, the University of Maine System accounts for 1,639 of the 4,609 publications (36 percent), with The Jackson Laboratory accounting for 831 publications (18 percent), and the Maine Medical Center accounting for an additional 466 (10 percent).

Similar to the grants analysis, publications also show a strong context in the broadly defined area of "environmental sciences," which includes ecology, earth sciences, and aquatic sciences (Table 5).

Table 5 Maine Publications Fields with 50 or More Publications

RESEARCH FIELD	NUMBER OF PUBLICATIONS
ENVIRONMENT/ECOLOGY	398
EARTH SCIENCES	380
AQUATIC SCIENCES	378
MOLECULAR BIOLOGY & GENETICS	239
PLANT SCIENCES	221
ANIMAL SCIENCES	193
MEDICAL RESEARCH, ORGANS & SYSTEMS	184
BIOLOGY	139
NEUROSCIENCES & BEHAVIOR	132
CELL & DEVELOPMENTAL BIOLOGY	129
BIOCHEMISTRY & BIOPHYSICS	123
MULTIDISCIPLINARY	118
ENDOCRINOLOGY, NUTRITION & METABOLISM	117
CARDIOVASCULAR & HEMATOLOGY RESEARCH	110
IMMUNOLOGY	107
MATERIALS SCIENCE & ENGINEERING	101
MEDICAL RESEARCH, DIAGNOSIS & TREATMENT	99
MEDICAL RESEARCH, GENERAL TOPICS	90
CARDIOVASCULAR & RESPIRATORY SYSTEMS	87
MICROBIOLOGY	76
PHYSICS	76
ANIMAL & PLANT SCIENCE	72
EXPERIMENTAL BIOLOGY	72
ENDOCRINOLOGY, METABOLISM & NUTRITION	68
PHARMACOLOGY & TOXICOLOGY	68
PHYSICAL CHEMISTRY/CHEMICAL PHYSICS	67
MATHEMATICS	62
ANESTHESIA & INTENSIVE CARE	61
PUBLIC HEALTH & HEALTH CARE SCIENCE	57
APPLIED PHYSICS/CONDENSED MATTER	54
RESEARCH/LABORATORY MEDICAL TECHNOLOGY	54
GENERAL & INTERNAL MEDICINE	53
UROLOGY & NEPHROLOGY	52
AGRICULTURE/AGRONOMY	51
SPECTROSCOPY/INSTRUMENTATION	51
FOOD SCIENCE/NUTRITION	50
REPRODUCTIVE MEDICINE	50

Source: Thomson Current Content Connect Database; Battelle Calculations

Table 6 provides details of the publications by institution and field.

Table 6 Leading Publication Fields (with 15 or more papers) by Maine Institutions

Institution	Field	Total
Bates College	MATHEMATICS	15
Bowdoin College	PHYSICS	32
	ENVIRONMENT/ECOLOGY	20
	CHEMISTRY & PHYSICS, PURE & APPLIED	16
	PLANT SCIENCES	16
University of Maine	EARTH SCIENCES	260
	ENVIRONMENT/ECOLOGY*	224
	PLANT SCIENCES	157
	AQUATIC SCIENCES*	195
	MATERIALS SCIENCE & ENGINEERING	92
	ANIMAL SCIENCES	68
	PHYSICAL CHEMISTRY/CHEMICAL PHYSICS	59
	BIOLOGY*	58
	FOOD SCIENCE/NUTRITION	39
	AGRICULTURE/AGRONOMY	39
	MULTIDISCIPLINARY	34
	MECHANICAL ENGINEERING	29
	CURRENT BOOK CONTENTS	29
	APPLIED PHYSICS/CONDENSED MATTER	28
	SPECTROSCOPY/INSTRUMENTATION	24
	ENTOMOLOGY/PEST CONTROL	23
	PHYSICS	21
	CIVIL ENGINEERING	21
	OPTICS & ACOUSTICS	20
	NEUROSCIENCES & BEHAVIOR	19
	MICROBIOLOGY*	36
	MATHEMATICS	19
	INSTRUMENTATION & MEASUREMENT	19
	MOLECULAR BIOLOGY & GENETICS	18
	ENVIRONMENTAL ENGINEERING & ENERGY	17
	EXPERIMENTAL BIOLOGY	16
*** Includes the Darling Center**	CHEMISTRY	15
	CHEMICAL ENGINEERING	14
University of New England	NEUROSCIENCES & BEHAVIOR	19
University of Southern Maine	PUBLIC HEALTH & HEALTH CARE SCIENCE	20
	ENVIRONMENT/ECOLOGY	18
	HEALTH CARE SCIENCES & SERVICES	17
Bigelow Laboratory for Ocean Sciences	AQUATIC SCIENCES	56
	EARTH SCIENCES	24
Foundation for Blood Research	MEDICAL RESEARCH, DIAGNOSIS & TREATMENT	23
Jackson Laboratory	MOLECULAR BIOLOGY & GENETICS	180
	MEDICAL RESEARCH, ORGANS & SYSTEMS	86
	CELL & DEVELOPMENTAL BIOLOGY	80

Institution	Field	Total
	IMMUNOLOGY	75
	BIOCHEMISTRY & BIOPHYSICS	60
	ENDOCRINOLOGY, NUTRITION & METABOLISM	55
	CARDIOVASCULAR & HEMATOLOGY RESEARCH	47
	MULTIDISCIPLINARY	46
	NEUROSCIENCES & BEHAVIOR	33
	ENDOCRINOLOGY, METABOLISM & NUTRITION	29
	ANIMAL SCIENCES	27
	HEMATOLOGY	22
	MEDICAL RESEARCH, DIAGNOSIS & TREATMENT	22
	DERMATOLOGY	21
	CURRENT BOOK CONTENTS	20
	BIOLOGY	19
	ONCOGENESIS & CANCER RESEARCH	18
	MEDICAL RESEARCH, GENERAL TOPICS	16
	ANIMAL & PLANT SCIENCE	15
Maine Medical Center	ANESTHESIA & INTENSIVE CARE	55
	CARDIOVASCULAR & RESPIRATORY SYSTEMS	50
	CARDIOVASCULAR & HEMATOLOGY RESEARCH	41
	MEDICAL RESEARCH, ORGANS & SYSTEMS	39
	UROLOGY & NEPHROLOGY	38
	MEDICAL RESEARCH, DIAGNOSIS & TREATMENT	36
	MEDICAL RESEARCH, GENERAL TOPICS	30
	GENERAL & INTERNAL MEDICINE	27
	RADIOLOGY, NUCLEAR MEDICINE & IMAGING	26
	REPRODUCTIVE MEDICINE	25
	BIOCHEMISTRY & BIOPHYSICS	24
	PEDIATRICS	22
	SURGERY	19
	CELL & DEVELOPMENTAL BIOLOGY	16
Mt. Desert Island Biological Laboratory	ANIMAL SCIENCES	29
	PHYSIOLOGY	25
	ANIMAL & PLANT SCIENCE	21
	EXPERIMENTAL BIOLOGY	20
	BIOLOGY	19
St. Joseph Hospital	ENDOCRINOLOGY, NUTRITION & METABOLISM	17

3.4 Patent Analysis

Measuring or analyzing industrial innovation in a quantitative context is difficult at best. However, the use of patent data provides a surrogate approach to understanding those innovations and intellectual property that industrial organizations, research institutions, and general inventors deem significant enough to register and protect. Furthermore, examining recent patent activity, instead of only existing product lines and market shares, provides some insight into firms' current R&D areas. Three types of patents are defined by the U.S. Patent and Trademark Office (USPTO):[4]

- **Utility** patents, which may be granted to anyone who invents or discovers any new and useful process, machine, article of manufacture, or composition of matter, or any new and useful improvement thereof
- **Design** patents, which may be granted to anyone who invents a new, original, and ornamental design for an article of manufacture
- **Plant** patents, which may be granted to anyone who invents or discovers and asexually reproduces any distinct and new variety of plant.

Additionally, patents have two geographic bases: the location of the inventors and the location of the assignee. Battelle used the location of the *inventor* for this analysis (i.e., one or more of the inventors had a Maine address) to best understand the research and innovation strengths located in the state.

Patent records were obtained from the Delphion patent analysis database. Patents from January 1, 2002 through May 31, 2007 were included. During this period, Maine's inventors contributed to 1,188 patents. Table 7 breaks down these patents into the three patent types, illustrating the overwhelming number and percentage of utility patents.

Table 7 Breakdown of Utility, Design, and Plant Patents for Maine

Patent Type	Number of Maine Patents, 1/2002–5/2007	% Share of Maine's Invented Patents
Utility	1,115	94%
Design	71	6%
Plant	2	-
Grand Total	1,188	100%

Source: USPTO data, collected through Thomson Delphion patent analysis database.

It is important to note that of the 1,188 Maine "invented" patents only 345 were assigned to Maine-headquartered companies with an additional 221 directly assigned to the Maine individual inventor (patents not assigned to a company/institution).

Table 8 provides the key Maine-based assignees of the 345 patents. Of those patents assigned to Maine-based companies and organizations, Fairchild Semiconductor accounts for the most patents both invented in Maine **and** assigned to a Maine company.

[4] See http://www.uspto.gov/web/offices/pac/doc/general/index.html#patent.

Table 8 Maine-based Companies with 4 or More Patents

Maine-Based Companies	Number of Maine Patents, 1/2002–5/2007
Fairchild Semiconductor Corporation	45
IDEXX Laboratories, Inc.	28
MariCal, Inc.	17
University of Maine	12
Imagineering, Inc.	9
Vishay Sprague, Inc.	7
Maine Medical Center Research Institute	6
Tex Tech Industries, Inc.	6
The Jackson Laboratory	6
Bath Iron Works Corporation	5
Neutar, LLC	5
Steag HamaTech, Inc.	5
RF Technologies Corporation	4
Riley Medical, Inc.	4
Sagoma Plastics Corporation	4
Thos. Moser Cabinetmakers	4
Tibbetts Industries, Inc.	4
Stillwater Scientific Instruments	4

Table 9 further examines the Maine patents by detailing those patent classes with 10 or more patents during the period. The patents are grouped by patent class name as some patent classes have more than one class number, e.g. Surgery. The importance of the biosciences can be seen due to the fact that the three largest patent classes are all in the bioscience/medical realm.

Table 9 Maine Patents- Classes with 10 or More Patents

U.S. Patent Class Name	Number
Chemistry: molecular biology and microbiology	47
Surgery	38
Drug, bio-affecting and body treating compositions	37
Stock material or miscellaneous articles	26
Communications: radio wave antennas	24
Electricity: electrical systems and devices	22
Printing	22
Furnishings	21
Animal husbandry	19
Miscellaneous active electrical nonlinear devices, circuits, systems	18
Special receptacle or package	18
Data processing: measuring, calibrating, or testing	17
Ships	17
Wave transmission lines and networks	17
Boots, shoes, and leggings	15
Measuring and testing	15
Abrading	14
Land vehicles	14
Semiconductor device manufacturing: process	14
Chemistry: analytical and immunological testing	13
Organic compounds -- part of the class 532-570 series	13
Rotary kinetic fluid motors or pumps	13
Metal working	12
Active solid-state devices (e.g., transistors, solid-state diodes)	11
Adhesive bonding and miscellaneous chemical manufacture	11
Multiplex communications	11
Valves and valve actuation	11
Data processing: generic control systems or specific applications	10
Electrical connectors	10
Games using tangible projectile	10
Liquid purification or separation	10
Oscillators	10
Static structures (e.g., buildings)	10

Source: Delphion Patent Database; Battelle Calculations

Looking beyond the three leading patent classes, a strong context in advanced communications and computers/information technology (including semiconductors) is also present.

3.5 Analysis of Knowledge Clusters

To develop a deeper quantitative assessment of Maine's research strengths and key themes that transcend institutional, research and innovation boundaries, Battelle conducted a specialized cluster analysis using textual information from recent research grants awarded to organizations in the state, abstracts of papers appearing in recent peer-reviewed journals and publications, and patents assigned to Maine companies, institutions, or individuals. For purposes of this analysis, we use the term "clusters" differently than used in the overall study. In this context, "R&D clusters" are groupings of papers, patents, and grants that have consistent themes or subjects that are identified using the methods discussed below.

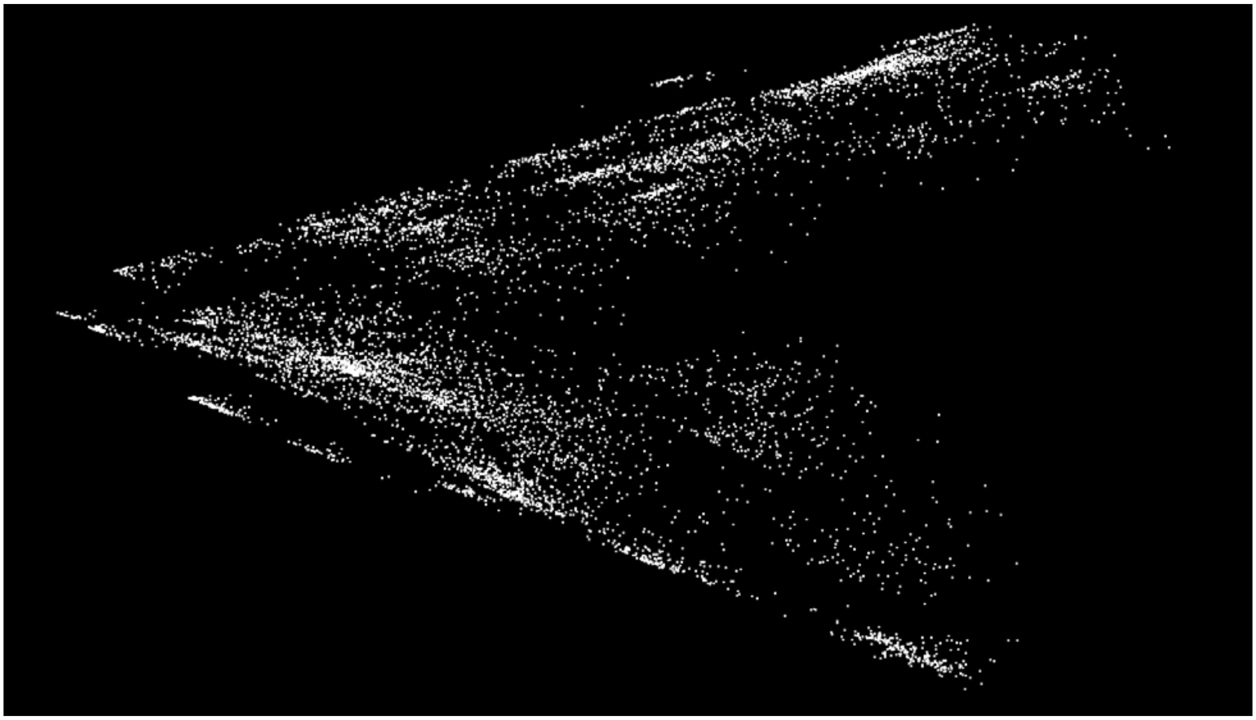
The identification of R&D clusters uses a Battelle-developed data-mining/text cluster tool, In-Spire™. Using this software tool, we examined how grants, publications, and patents relate to one another based on the actual research or innovation described within the textual information collected. This process provides a unique perspective on the research context. In some instances, a thematic strength may revolve around a topic (e.g., cancer, materials, energy), linking together a variety of research approaches, or around a technique (e.g., nanotechnology), focusing on the development and application of such techniques towards a host of research domains. One unique aspect of the In-Spire™ analysis is the ability to identify or highlight unique niches within the grant, publication, and patent data. Battelle has applied this tool in other state and regional studies and in its own efforts to identify technology focus areas within its overall research activities across its many offices and laboratories.

Battelle attempted to include all federal research grants (including grant title, grant abstract, and key words) from FY2002 to date. However, public access to research grants from key agencies such as the U.S. Department of Defense (DOD), U.S. Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA) is unavailable. Some of these grant records were available through the RAND Corporation's Research and Development in the U.S. database (RaDiUS). However, due to data time lags, only data from FY2002 to FY2005 are available. Furthermore, due to the security nature of much of the research funded through these departments, many specific awards are not reported, and many are reported but with little useful textual information for cluster analysis purposes. For the purposes of this analysis, the Battelle analysts included for each record the title, abstract/summary information, and key words/thesaurus terms/patent class titles (when available).

Through the grouping process, In-Spire™ establishes the R&D clusters based on the specific dataset characteristics and key parameters developed by the analysts. The Battelle team analyzed the R&D cluster construct and the content of the individual grant awards or patents to interpret and name stand-alone clusters or to group a set of closely aligned clusters into "*meta-clusters*." While these meta-clusters are often the key themes of the dataset under analysis, it is possible to have key themes made up of a single cluster consisting of a large number of closely aligned individual grants or patents.

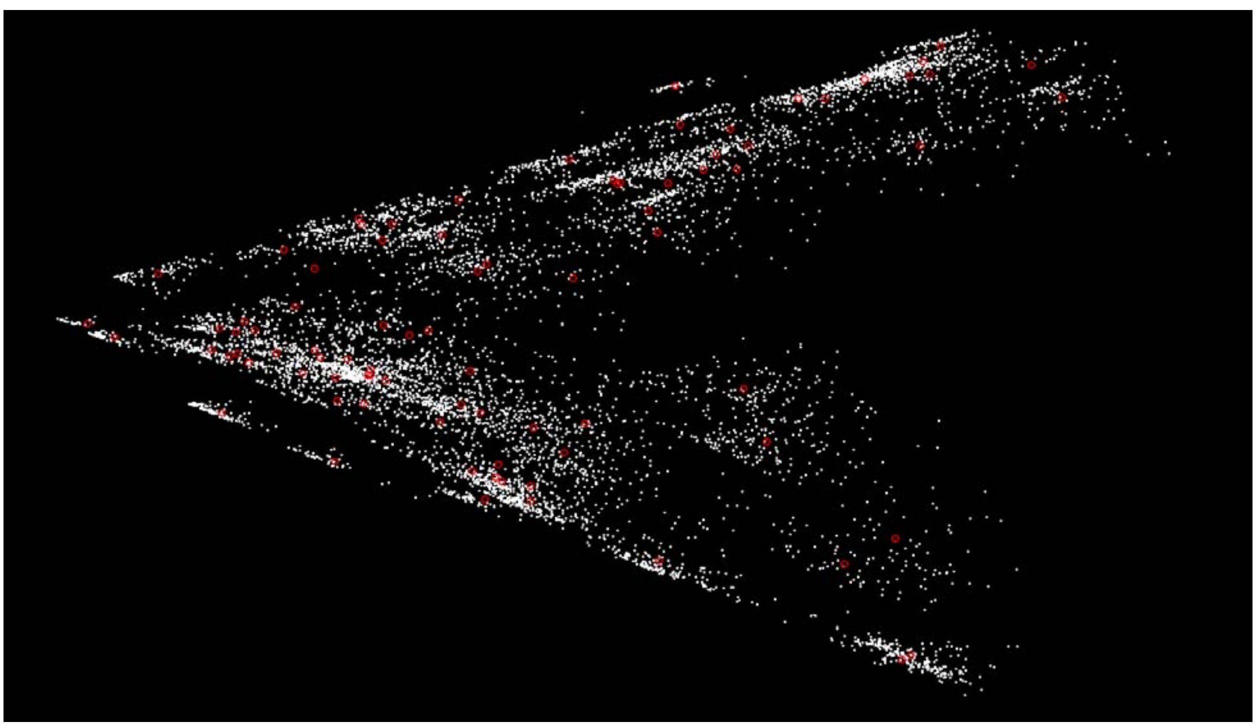
Figure 3 shows the initial display or cluster "galaxy" of the 7, 312 text data records used in the cluster analysis. In the process of clustering the significant amount of textual data included in this analysis, some textual information did not purposefully "cluster" into one of the key themes, yet was "forced" into a cluster due to the numeric algorithms used by the tool. *It is important to remember that this figure is a 2-dimensional portrayal of a multi-dimensional data space; hence typical X-Y coordinate basis do not necessarily impart any meaning to the figure.*

Figure 3 Initial In-Spire Galaxy of Maine Research and Innovation Text Data



Overall, 85 individual clusters were identified through the use of In-Spire™. The centroids of these clusters are shown as red circles in Figure 4.

Figure 4 All Maine Research and Innovation Text Records with 85 Cluster Centroids (Red Circles)



A significant number of records dropped out of the analysis as artifacts, and hence do not appear in the final cluster diagram.[5] The Battelle analysts examined the cluster constructs and the content of the individual records to interpret stand-alone clusters and to group a set of closely aligned clusters into "meta-clusters." While these meta-clusters are often the key themes of the dataset under analysis, it is possible to have key themes made up of a single cluster consisting of a large number of closely aligned individual records.

Figure 5, on the next page, shows the final cluster diagram in which 35 valid clusters were grouped into 19 meta-clusters.

[5] "Artifact clusters" occur when records form into a few large clusters based on mundane words or into a large number of very small clusters around non-descript terms or terms that have multiple meanings.

Figure 5 Key Maine R&I Clusters Grouped into 19 Meta Clusters

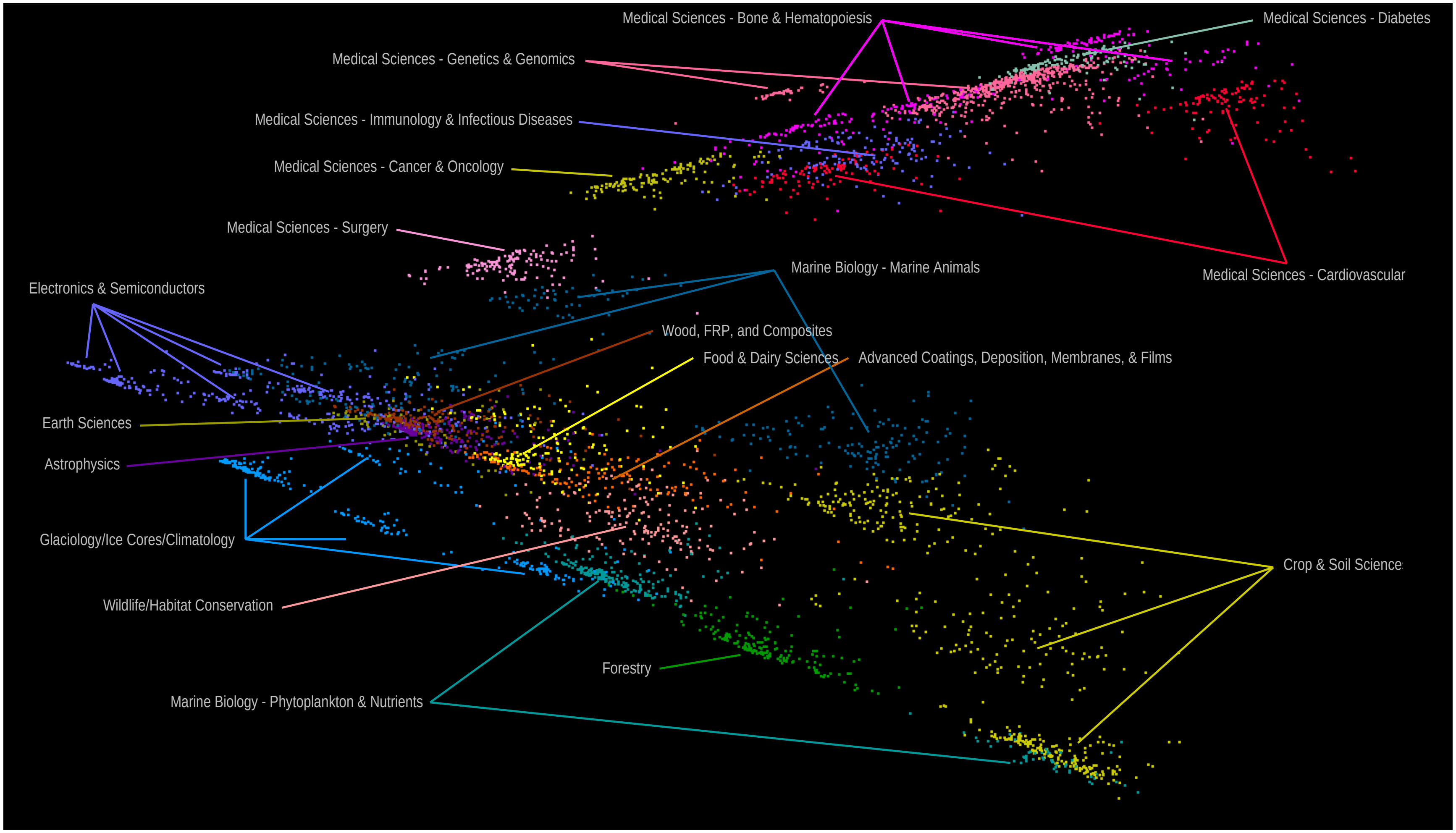


Table 10 details the meta-clusters and provides information regarding the number of records in each. In total, 61 percent of the records were connected to a cluster/meta-cluster. Overall, and not surprisingly, medical sciences dominate the cluster analysis due to the large numbers of medical/health grants (primarily NIH) and the large numbers of publications. In total, the six medical sciences-related meta-clusters account for 1,433 records. The Medical Sciences – Genetics & Genomics meta-cluster alone accounts for the largest number or records with 542, or 12 percent, of the total clustered records. The second largest single meta-cluster, however, is Crop & Soil Sciences containing 458 records.

Table 10 Records in Each Meta-Cluster

Meta-Cluster	Number of Clusters in Meta-Cluster	Number of Records in Meta-Cluster
Advanced Coatings, Deposition, Membranes, & Films	1	166
Astrophysics	1	224
Crop & Soil Sciences	3	458
Earth Sciences	1	78
Electronics & Semiconductors	5	395
Food & Dairy Sciences	1	193
Forestry	1	188
Glaciology/Ice Cores/Climatology	4	271
Marine Biology - Marine Animals	3	372
Marine Biology - Phytoplankton & Nutrients	2	261
Medical Sciences - Bone & Hematopoiesis	4	264
Medical Sciences - Cancer & Oncology	1	134
Medical Sciences - Cardiovascular	2	220
Medical Sciences - Genetics & Genomics	2	542
Medical Sciences - Immunology & Infectious Diseases	1	138
Medical Sciences - Surgery	1	135
Wildlife/Habitat Conservation	1	206
Wood, FRP, and Composites	1	250
Meta-Cluster Totals	35	4,495
Share of Total Records/Clusters	41%	61%

Marine Biology is represented by two meta-clusters: one focused on marine animals (372 records) and one focused on phytoplankton & nutrients (261 records). Advanced Materials, accounting for a combined 416 records, is also represented in the analysis with two meta-clusters: Advanced Coatings, Deposition, Membranes, & Films; and Wood, FRP (Fiber Reinforced Polymers), and Composites.

3.6 Connections between Maine's Research and Innovation Strengths and Technology Sectors

Taking these four analyses together provides a strong picture of the research and innovation strengths of the state of Maine. However, as is the case with probably every state, not all of these strengths are geared toward supporting the existing industry in the state. Table 11 provides a mapping of connection intensity found in these four analyses to Maine's existing industry cluster structure.

Table 11 Connections Between Maine's Research and Innovation and Technology Sectors

Industry Sector	Grants	Publications	Patents	Knowledge Cluster Analysis
Forest Products & Agriculture: Crop, Food, & Beverage Production	✓✓	✓✓		✓✓
Forest Products & Agriculture: Lumber, Paper, & Wood Products	✓✓	✓✓✓	✓	✓
Marine Technology & Aquaculture	✓✓✓	✓✓✓		✓✓
Biotechnology	✓✓✓	✓✓✓	✓✓✓	✓✓✓
Composites & Advanced Materials	✓	✓✓	✓✓	✓✓
Manufacturing: Fabricated Metals & Machinery			✓✓	
Manufacturing: Computer & Electronics	✓		✓✓✓	✓✓
Information Technology	✓		✓✓	
Engineering & Other Scientific/Technical Services				
Environmental Services & Alternative Energy Generation	✓	✓✓		

Note: Number of ✓ indicate level of connection intensity, three ✓s indicating extremely strong topical connection to the industry cluster.

As shown in Table 11, Biotechnology (medical sciences) has substantial documented research and innovation efforts that are currently, or could be, supporting efforts in this industry cluster. The Marine Technology & Aquaculture cluster has a potentially strong research base on which to build, yet the limited patent activity shows that Maine's industry may not currently be in a position to leverage the research or the research is much more basic (instead of applied) in nature. With the exception of Engineering & Other Scientific/Technical Services all of the remaining industry clusters have some potential connections to the research and innovation base of Maine.

3.7 Key Research Capacities in Maine

The analysis above examines Maine's research strengths in terms of the output of its research activities in recent years. Success in the highly competitive world of research is best judged by this type of analysis which focuses on the outcomes of the research process as they are judged in peer review processes such as grants and publications and in legal processes such as patents. However, another perspective on research strengths is to look at distinctive research capacities within Maine, that is, the availability of specific research organizations which play a unique role within their field.

Maine is home to a number of what may be considered world class or nationally distinctive research organizations. There are also individual researchers who are highly distinctive in their field throughout higher education, private research, and private commercial firms. It is somewhat easier to discuss the organizations which are distinctive in Maine as the population of key individuals is perpetually changing. These organizations are divided between those which are private non-profit research organizations and those which are part the University of Maine

Among the former, the most important of course is **The Jackson Laboratory** in Bar Harbor. Founded in 1929, the Jackson Laboratory is one of a very small number of centers in the world that focuses on mammalian genetics, specifically the genetics of mice, which are a key "model" for use in genetic research. Jackson houses the world's largest collection of research mice and the genetic information about them. The Laboratory has also greatly expanded its health research in areas such as cancer, aging, and neurological disorders. It is the largest recipient of biomedical grants in Maine and one of the largest recipients of NIH grants in the country, particularly outside California and Massachusetts. In partnership with the University of Maine and other institutions outside of Maine, Jackson Laboratory is a growing educational center for research in genetics, genomics, and related fields where new researchers are trained at the pre-doctoral and post-doctoral levels.

As discussed below in the chapter on biotechnology, The Jackson Laboratory plays a key role in Maine by virtue of its size and its expanding importance in many aspects of biomedical and biological research. It is an institution which is focused on research at the most basic scientific levels, but which is increasingly finding a role in the development of commercial products aimed at the biomedical research industry itself, as evidenced by the first commercial spin off company, Bar Harbor Biotechnology, a firm which has been established to market new techniques in bioinformatics.

The **Mount Desert Island Biological Laboratory** is another example of a research organization which has been in Maine for many years (it was founded in 1898). Like The Jackson Laboratory, it was begun with a focus in a particular research area and has expanded its activities greatly in recent years. The focus of MDIBL's research has been the study of the way marine organisms function as a model for human systems. For example, much research has been focused on fish kidneys to better understand how human kidneys work. In the last 20 years, the Laboratory has increased its year round activities, expanded its education connections in Maine, and focused more attention on genetics, molecular biology, and stem cells in a variety of marine organisms. MDIBL retains a unique role in using the most advanced areas of biological research in marine organisms as a pathway to better understanding biological processes in general and their relevance for human health in particular.

The **Bigelow Laboratory for Ocean Sciences** in Boothbay Harbor was founded in 1974 and is part of the large marine science community in Maine that is discussed in the chapter on marine technology. Bigelow is home to a number of research programs in oceanography and marine science, but has a particularly strong role in research on phytoplankton, the most essential element of the marine food web. This research led to the creation of new measuring technologies that have been successfully commercialized.

Two more recently established private research organizations are in the process of defining their unique contributions to their fields. The **Maine Institute for Human Genetics and Health** is a newly formed organization centered on Eastern Maine Healthcare Systems and with ties to The Jackson Laboratory and the University of Maine. MIHGH intends to focus on the direct implications of genetic and related research for clinical applications through interdisciplinary research. An example is combining environmental health research with genetic research to better understand the distribution of risks for cancer.

The **Gulf of Maine Research Institute** is a recent addition to Maine's ocean science community. GMRI has adopted a unique mission to combine research, education, and the convening of stakeholders in marine policy issues. GMRI is thus one of a small number of scientific research institutions that is making connections to decision makers and publics an integral part of the research process in the hopes of improving the use of scientific research in decision making. GMRI is also seeking to significantly expand its research into new areas such as the application of nanotechnologies to marine areas. These may become unique areas of strength in the future.

The **University of Maine** is the home of a number of major and unique researchers and research organizations. There are wide ranging capacities in the fields of environmental, forest, agricultural, marine, and biological research as evidenced by the outputs discussed earlier in this chapter. Five research centers at UM have unique roles that are particularly connected to the process of cluster development in Maine.

The **Advanced Engineered Wood Composites Laboratory and Advanced Structures and Composites Laboratory** are perhaps the best known of these centers. The AEWC, which is the largest such center outside of the private sector in the U.S., is a key resource for the composites and advanced materials cluster in Maine. Composite materials are the subject of a great deal of research around the world. The University of Maine's focus is on the use of wood in the making of composite materials that are lighter, stronger, and more resilient than wood or other materials alone. Research has recently focused on combining wood and plastics into new materials. The Laboratory is distinguished by its size (both physical plant and employment) and by the combination of research and product testing services that it offers. It is the only university-based composites centers whose product testing is accepted by building code agencies in the U.S. and worldwide. The Laboratory has demonstrated significant success in the development of technologies for defense and security related applications, and is considered a world leader in research into wood-nonwood composites. The Laboratory has won a number of national awards for its innovative use of wood, including the top prize from the American Composites Manufacturing Association.

The **Forest Bio-products Research Institute** extends the AEWC mission of finding new uses for wood to the development of a wide array of new products based on wood. Founded in 2006 with funding from the National Science Foundation FBRI is a key player in the development of new bio-fuels and bio-plastics (discussed in the chapter on forest products and agriculture). The Institute's research program is distinctive in bringing together research on forestry, chemical and biological engineering, and pulp and paper technology. The goal is a sustainable wood based economy in which new products for new markets in fuels, chemicals, and materials are produced while the health of the forest ecosystem which underpins the new products remains strong. The

Initiative's systems based approach to new forest products development through rapid development of demonstration projects in all three areas of fuels, chemicals, and materials is a unique aspect which shortens the path to commercialization. The FBRI, in cooperation with private sector partners, should establish itself as a major player in research into the systems of new product development from forests.

AEWC undertakes research in the formation of large composite materials suitable for the construction of everything from boats to bridges. At the other end of the spectrum is the **Laboratory for Surface Science and Technology (LASST)** which examines the properties of materials used in the making of much smaller products such as semiconductors and thin films. Like AEWC, LASST conducts research on its own as well as in cooperation with private sector firms on issues relating to surfaces, films, microelectronics, and sensors. LASST does R&D in the fields of surface/interface science and nanotechnology. There are a large number of nanotechnology research centers in the US, but only four in addition to the University of Maine focus specifically on surface science. These include research centers at the University of Virginia, Northwestern University, Rutgers University, and the University of Wisconsin-Milwaukee.

Among these centers, LASST is particularly distinctive in its focus on developing sensor technologies, ranging from the physics and chemistry of sensor surfaces and thin film coatings, to the design, fabrication, and testing of prototype sensor devices, to networking and data processing of sensor information in a diverse range of applications. There is no other comprehensive sensor technology center at another university in the US. In fact, the US lags behind Japan, Germany, and Italy in sensor development and commercialization. LASST has several multimillion dollar-funded efforts in chemical/biological sensors as well as similarly funded education training grants in sensor technology. Among LASST's assets is a 3500 sq. ft. state-of-the-art clean room micro/nano fabrication facility that has the ability to process bare wafers into complete prototype sensor devices. This versatile facility is unique and is used in collaboration with several industrial partners, including six spin-off companies that were incubated from LASST technology.

The National Center for Geographic Information and Analysis is a National Science Foundation-funded consortium of the University of Maine, the University at Buffalo, and the University of California at Santa Barbara. The Center is a key part of research in geospatial technologies at the University of Maine, and focuses particular attention on issues around the accuracy of GIS systems, the way people interact with GIS systems, and the development of approaches to dynamic modeling using GIS. This basic research in how GIS works and U Maine's connections to other major research institutions in this field provide a distinctive research capacity for Maine's growing community of GIS researchers and developers.

3.8 Summary

These analyses taken together describe the research and innovation base of Maine. The results indicate:

Significant research in medical sciences, marine sciences, crop & soil sciences, and forestry/environmental sciences

Strong grant and publication levels indicate these areas provide the most extensive research base within the state. However, the potential connections to Maine's industries and the translation of these areas into economic drivers for the state of Maine will take some additional work, as much of the research is "basic" in nature. Additionally, while the State's research enterprises demonstrate strengths in a full spectrum of marine sciences the translation of pieces of this vast research portfolio into "aquaculture" may require significant applied research efforts and both academic as well as private sector entrepreneurs. Finally, the volume of medical sciences research, due to The Jackson Lab, dwarfs existing biotechnology industry.

Research in wood/fiber-related composites is robust

The cluster analysis highlighted the Wood, FRP (Fiber Reinforced Polymer), and Composites as a research niche within the State. This (and, potentially, in combination with identified research strengths in Forestry and Advanced Coatings, Deposition, Membranes, & Films) provides the State with a uniquely "Maine" avenue to pursue advanced materials development that is the foundation for the composites and advanced materials sector.

Innovation in IT and manufacturing clusters is dominated by industry efforts/patents

While some academic research efforts exist, through the patent and cluster analysis it is apparent that much, if not most, of the innovation that occurs in the IT, computer, and manufacturing clusters is led and dominated by industry efforts.

Maine has distinctive research capacities in a number of fields directly related to its cluster strengths.

In addition to the wide ranging research strengths demonstrated by the outputs of research, Maine is home to a number of research institutions with distinctive capacities on which clusters can be built, especially in biomedical and biological research, composites and advanced materials, chemical engineering, forest management, and geographic information systems.

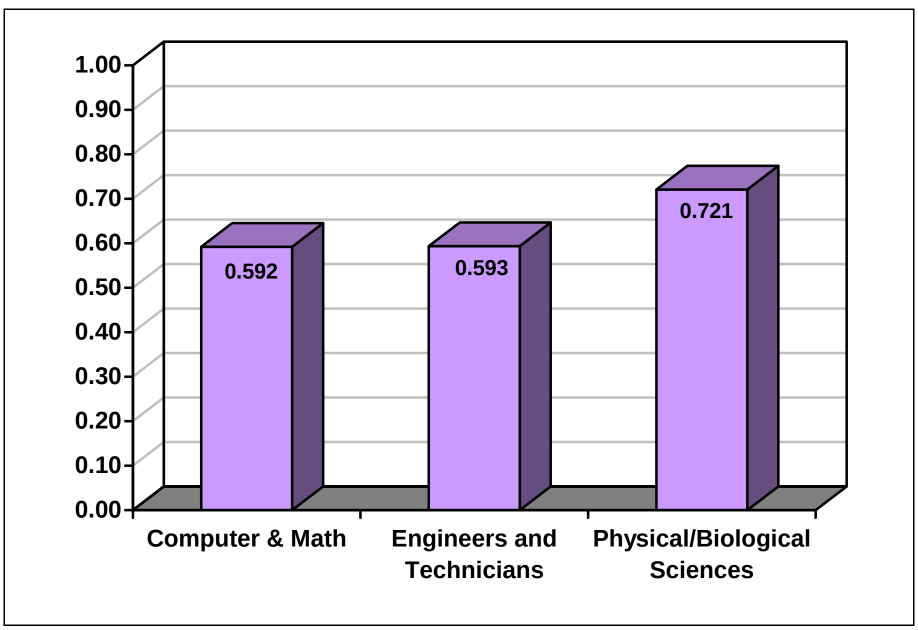
4. The Foundation: Human Resources for Technology Innovation

Examining the research strengths within Maine lays the groundwork for an understanding of the concept of clusters based on the knowledge and skills capacity of a region. Another way of assessing the knowledge and skills base is to examine the occupational strengths of Maine in relevant occupations. Clearly, a successful technology-based economy requires the skills of a wide variety of people. Business management, finance, marketing, and production skills are all critical, but at the bottom are the people in what is known as the STEM, or science, technology, engineering, and mathematics, occupations.

4.1 Trends in the STEM Workforce in Maine

For purposes of this analysis, the Occupational Employment Series of the U.S. Bureau of Labor Statistics is used.[6] Employment data typically examine employment by industry; analysis of each sector in this basis is discussed in the chapters on each technology sectors. Occupational analysis examines the distribution of occupational types across all industries. Data are classified according to the Standard Occupational Code (SOC), published by the Department of Labor. The analysis here uses data from three major groupings of the SOCs: computer and mathematical occupations, engineering and technicians, and physical & biological sciences. The detailed list of occupations in these categories is found in Appendix 2.

Figure 6 Specialization of Maine Economy in STEM Occupations:2006



[6] See http://www.bls.gov/oes/home.htm.

Overall, Maine is significantly less specialized in these occupations than the U.S. Figure 6 shows the specialization ratio[7] for the three major groups. Computer and math occupations and engineer/technicians occupations are at only about 60% of the level of the U.S. economy as a whole. Only in the physical and biological science occupations does Maine get a little closer to the national level at 72% of the U.S. level.

Figure 7 Growth in STEM Occupations 2000-2006

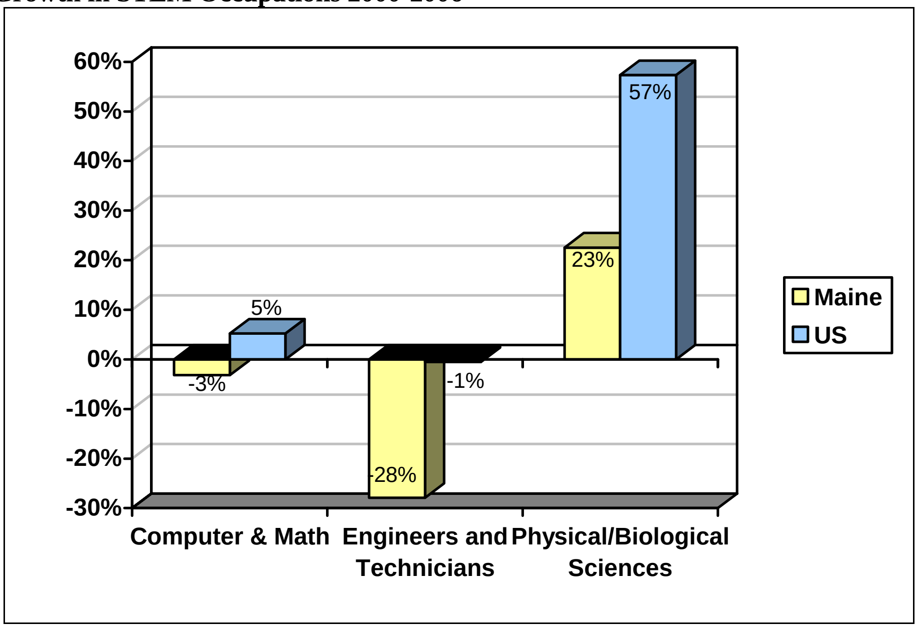


Figure 7 compares growth in these three major groups of occupations in Maine and the U.S. from 2000 to 2006. There was relatively little change overall in computer and math occupations in either the U.S. or Maine, but Maine showed a small decline while the U.S. showed a little growth. Engineering and technician occupations declined in both the U.S. and Maine, but Maine's decline was quite significant while that in the U.S. was negligible. Only in the scientific professions did both the U.S. and Maine show growth. Maine's growth of 23% was substantially in excess of total employment growth over the same period (1.8%), but also less than half the growth level of these occupations in the U.S.

Together, Figure 6 and Figure 7 suggest that Maine does have some strength and growth in scientific occupations, but engineering and technical occupations have undergone some important declines since 2000. Maine lags behind the nation in computer and mathematical occupations, and those jobs have declined somewhat; though there have not been large changes here or in the U.S. The question then becomes which occupations within these broad categories are strongest in Maine. This is explored in the following six figures.

Figure 8 Specialization Ratios: Computer and Math Occupations in Maine 2006

[7] Otherwise known as the location quotient, it is the ratio of the percent of the Maine economy in each occupation to the percent of the U.S. economy in that occupation. A value of 1 means that Maine has the same proportion of that occupation as in the U.S. A value less than 1 means Maine is less specialized in that occupation and more than 1 implies greater specialization.

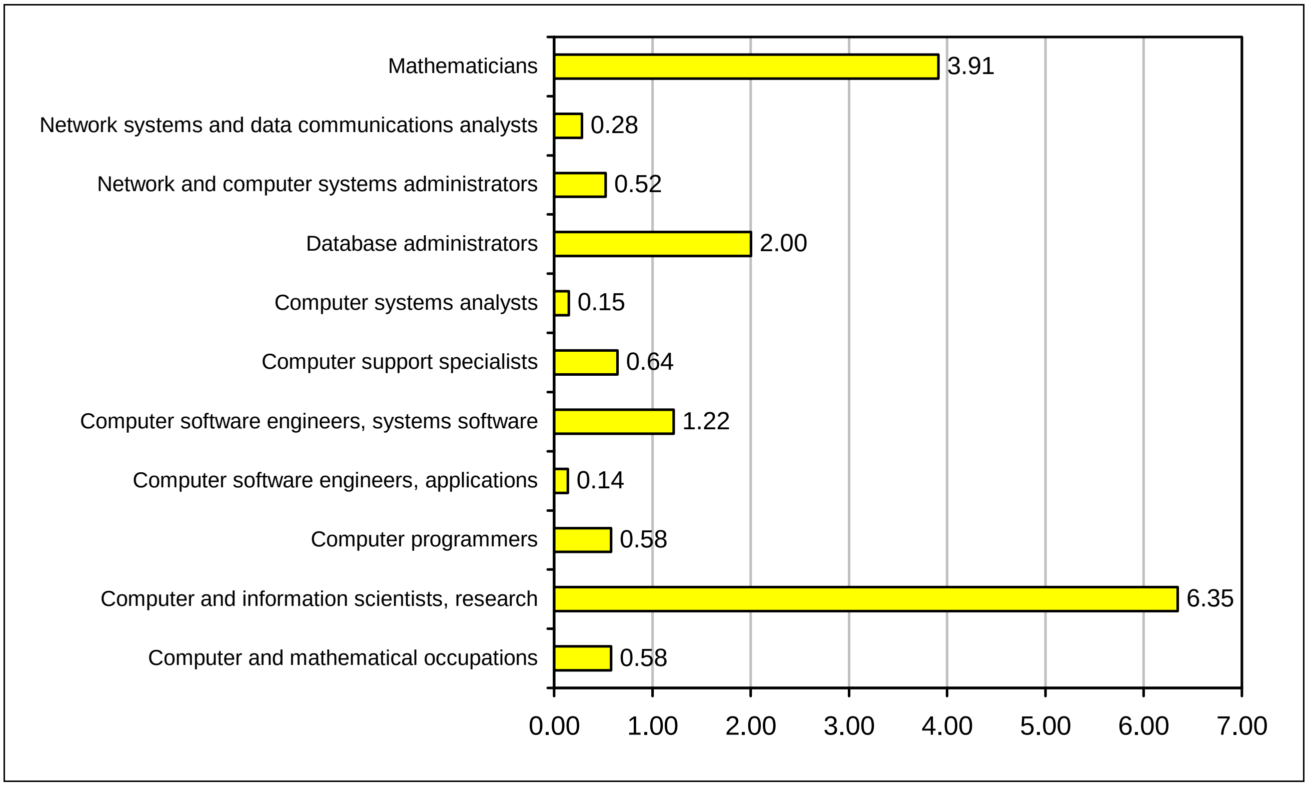


Figure 9 Growth in Computer and Math Occupations US and Maine 2000-2006

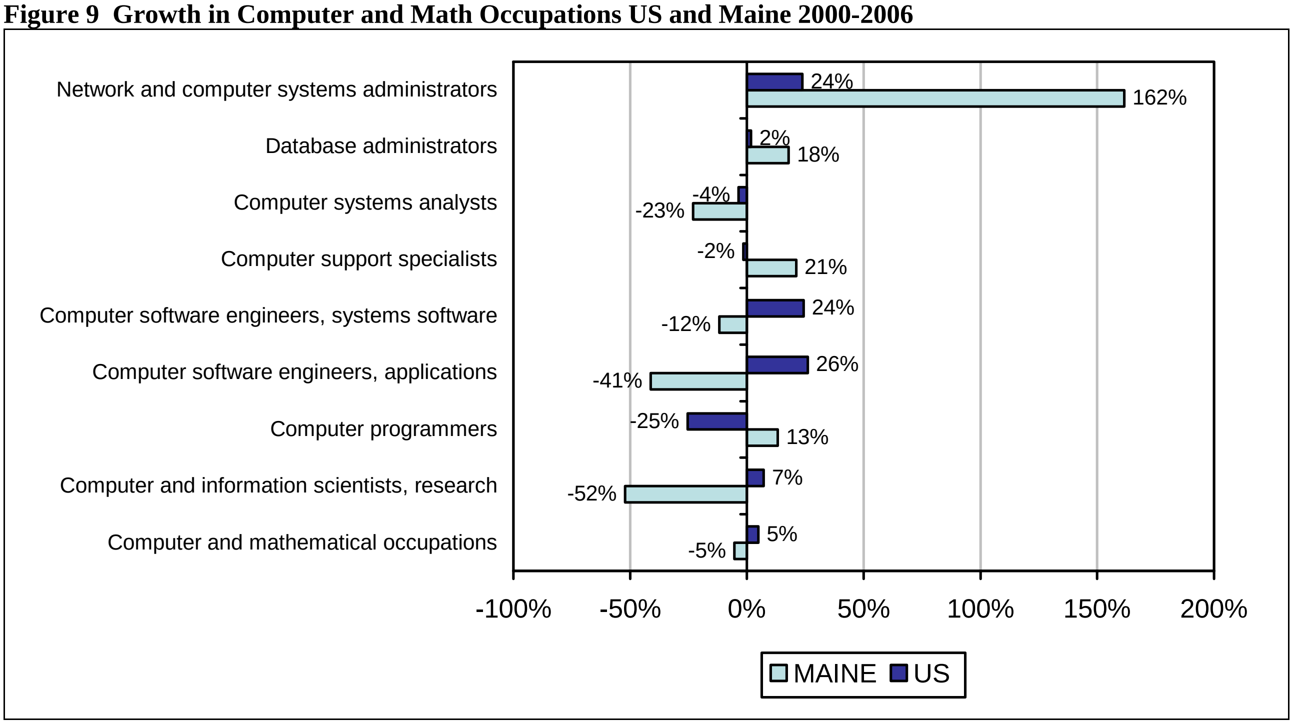


Figure 10 Specialization Ratio for Engineering and Technician Occupations in Maine 2006

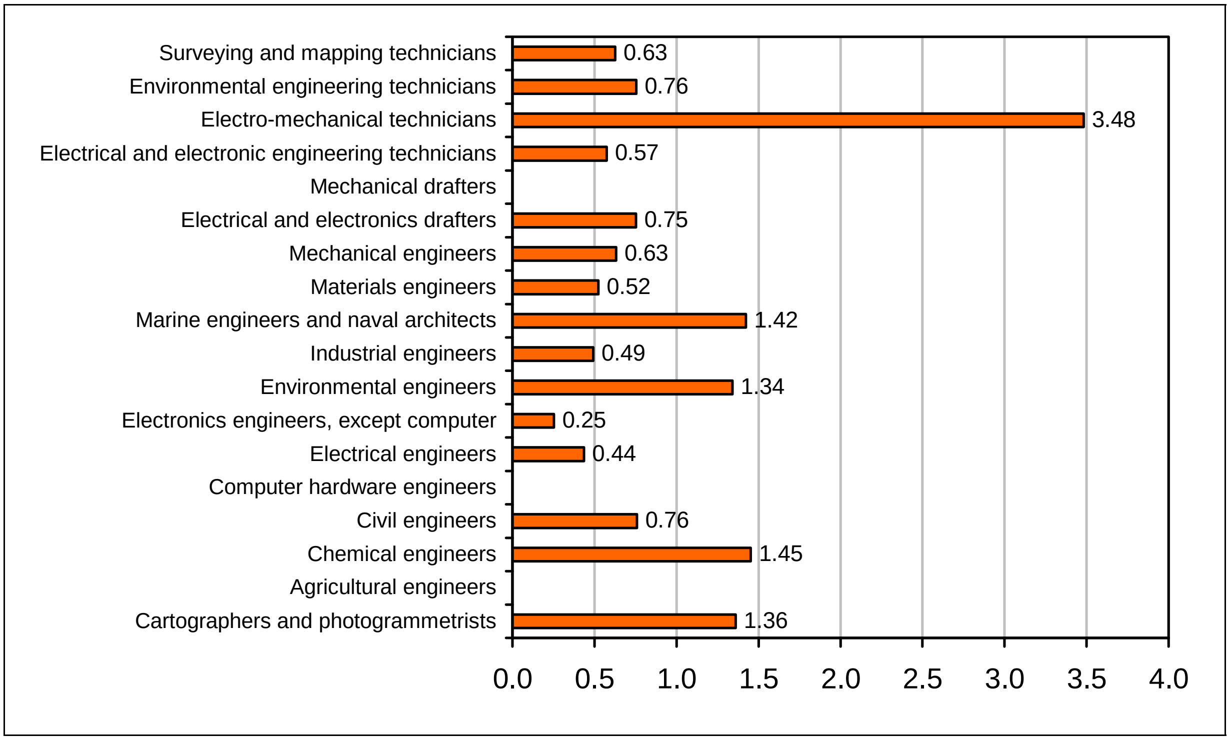


Figure 11 Growth in Engineering and Technician Occupations Maine and U.S. 2000-2006

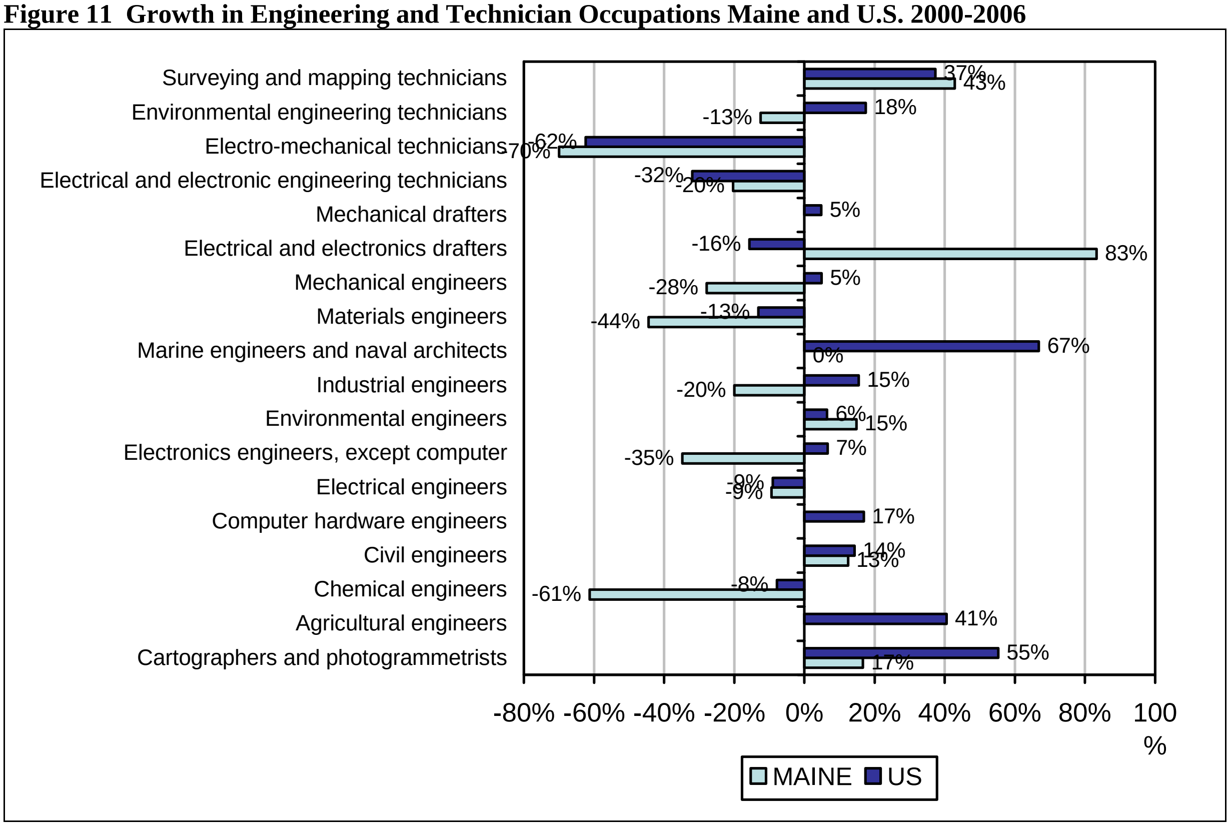


Figure 12 Specialization Ratio for Science Occupations in Maine 2006

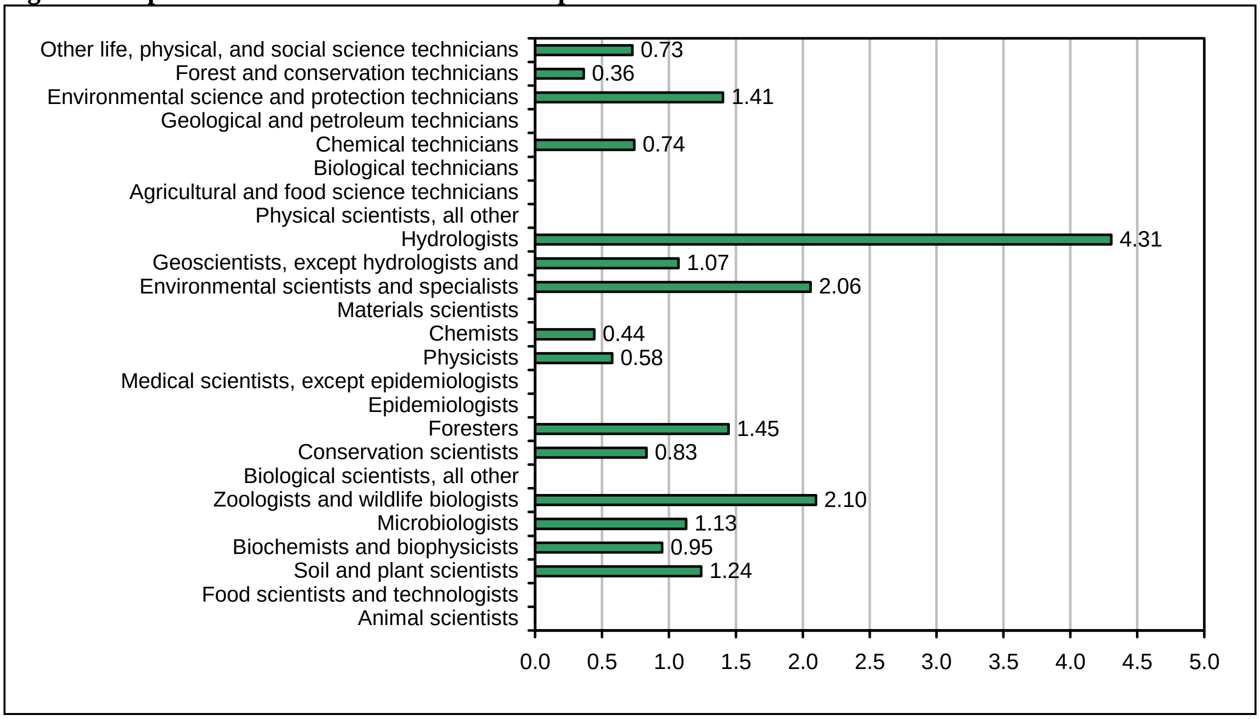
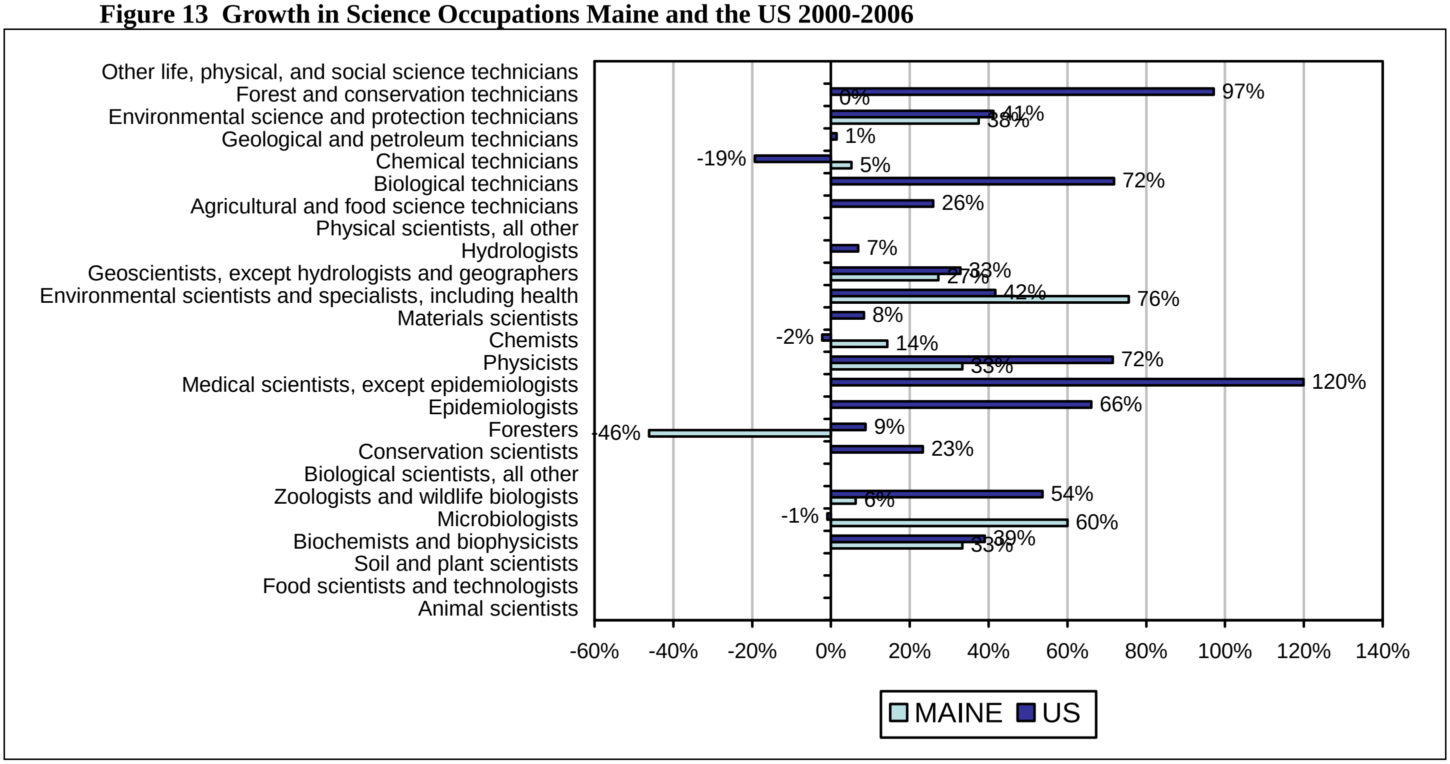


Figure 13 Growth in Science Occupations Maine and the US 2000-2006



Data for some occupations in either 2000 or 2006 are not available, so there are occupational categories in Figure 8 through

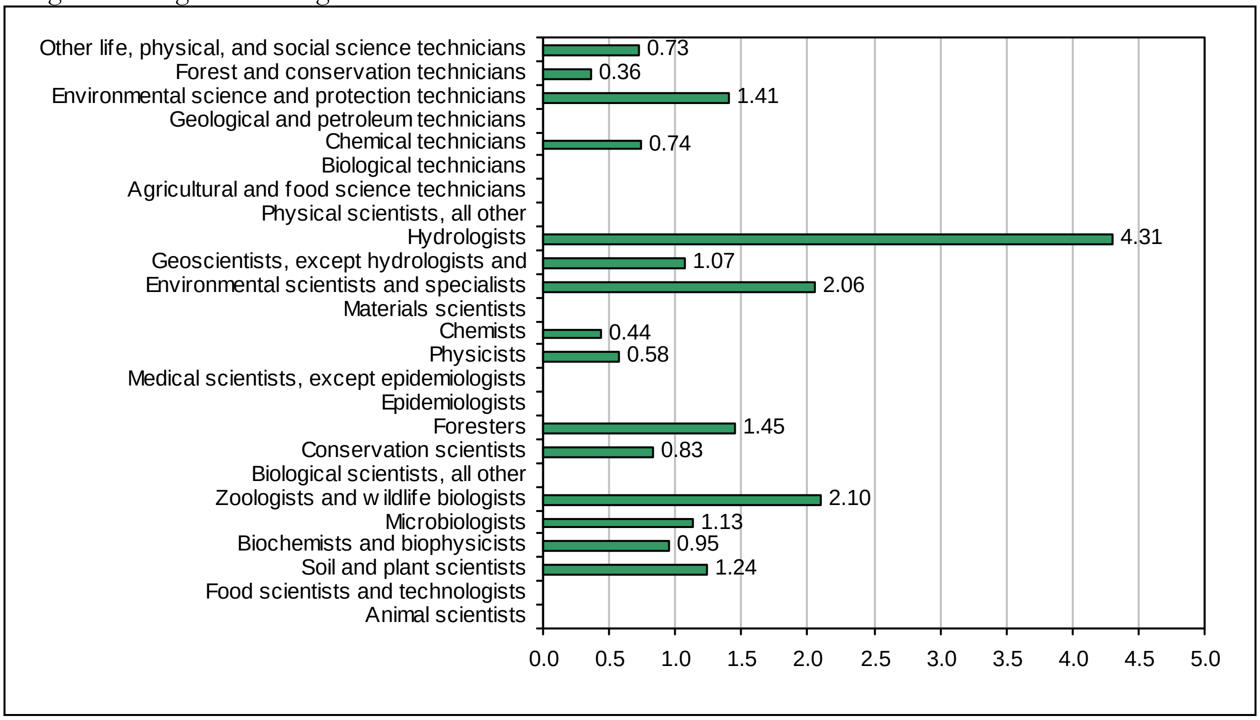


Figure **13** that have missing data. The missing data arises primarily from data suppressions required to preserve confidentiality of individual employers. This includes some categories in which the principal employment is at the University of Maine.

Among computer and math occupations, Maine has relative specializations in research computer scientists, database administrators, mathematicians, and software engineers. The fastest growing occupations in Maine are network and systems administrators, support specialists, and computer programmers. Maine saw declines in software engineers, computer scientists, systems analysts, and application development. These declines were in part associated with the "tech bust" of the early part of this decade. After a rapid growth in IT related occupations from 1995-2000 as the personal computer diffused rapidly throughout the economy, these occupations saw much slower growth in 2000-2006 in the wake of the ending in the spurt of Y2K-related investments and a national recession.

However, Maine saw absolute declines in many key occupations compared with growth in the U.S. For example, software applications engineers grew by 26% in the U.S. but declined by 41% in Maine. At the same time, Maine showed significant growth in database administrators and network administrators. Together these trends suggest that over the past six years, Maine has diffused computer related occupations needed for the management of organizations throughout the economy, but software and computer applications development in Maine has weakened.

Trends in engineering and technician occupations show some defined strengths for Maine: marine engineers and naval architects (not surprising given Maine's ship and boat building industries), chemical engineers (a specialty particularly associated with the pulp and paper industry), electro-mechanical technicians (associated with many manufacturing industries in Maine), and finally cartographers and photogrammetrists (a specialty associated with Maine's needs for large scale forest land management).

Growth in engineering and technician occupations reflects ongoing difficulties in the manufacturing sectors. Maine saw drops in a variety of engineering specialties, including mechanical, electro-mechanical, electrical-electronic, materials, industrial, and chemical engineers. Of these, electro-mechanical technicians, electrical-electronic engineers, and materials engineers also declined in the U.S. All of the other categories declined in Maine but not in the U.S. Maine did see growth in electrical-electronic drafters, environmental engineers, civil engineers, survey/mapping technicians, and cartographers/photogrammetrists. These upward trends are consistent with strengths in the environmental engineering sector and in a specialized subsector of IT dealing with geospatial analysis and geographic information systems.

The specialization and growth in GIS/geospatial analysis is consistent with the discussion in Chapter 8 on information technology, and with the finding in the 2001 cluster study that this area represented an area of strength within Maine. It is difficult to measure precisely this geospatial analysis capacity because the occupation categories do not distinguish between those who do survey and mapping technical work and cartographers who use computer systems and those who do not. However, the rapid diffusion of GIS and GPS (global positioning systems) technology through the spatial analysis community over the past decade means that relatively little traditional mapping, photo interpretation, and surveying is done without at least some IT assistance.

Analysis of the scientific occupations also points to some definite strengths and weaknesses in Maine. Occupations in which Maine specializes include environmental technicians and scientists, hydrologists, geoscientists, foresters, wildlife biologists, microbiologists, and soil & plant scientists. These are precisely the scientific fields one would expect to find in a heavily forested, natural resource dependent state. When growth is examined, the strengths and weaknesses become more apparent. Foresters have undergone a significant decline in Maine (even while growing in the rest of the U.S.). However, Maine is seeing growth comparable to the U.S. in biochemists and biophysicists, and is showing much faster growth in microbiologists, and environmental scientists and technicians. Geoscientists also showed strong growth in Maine. These trends indicate a shift in scientific specialties towards the environmental and biotechnology sectors and somewhat away from the natural resource management sectors, though these remain very important in Maine.[8] These trends are generally consistent with the analysis of research specializations in Chapter 3.

Another comparative perspective on Maine's STEM workforce is provided in Figure 14 through Figure 16. These compare Maine with six reference states selected for the purpose of this study. Appendix 1 contains a discussion of the selection of these reference states. These figures show the relative size of the employment in each state (the size of the bubble), the specialization relative to the U.S. (the position on the vertical axis), and the growth rate (position along the horizontal access). Bubbles positioned above the horizontal access show more specialization in the state; below indicates less specialization. Bubbles positioned to the right of the vertical line are growing faster than the U.S.; those to the left are growing slower.

The weakness in computer and math occupations growth in Maine is reinforced in this analysis. Maine is the only state to experience overall decline, while other states saw growth in these occupations. Maine is also the least specialized of the states. Maine is also the laggard among engineering and technical occupations in specialization. Maine's declines were less than those in Idaho, but the comparison with the other states is not particularly favorable. Among the sciences, Maine does at least join the other states in showing employment growth, and was ahead of

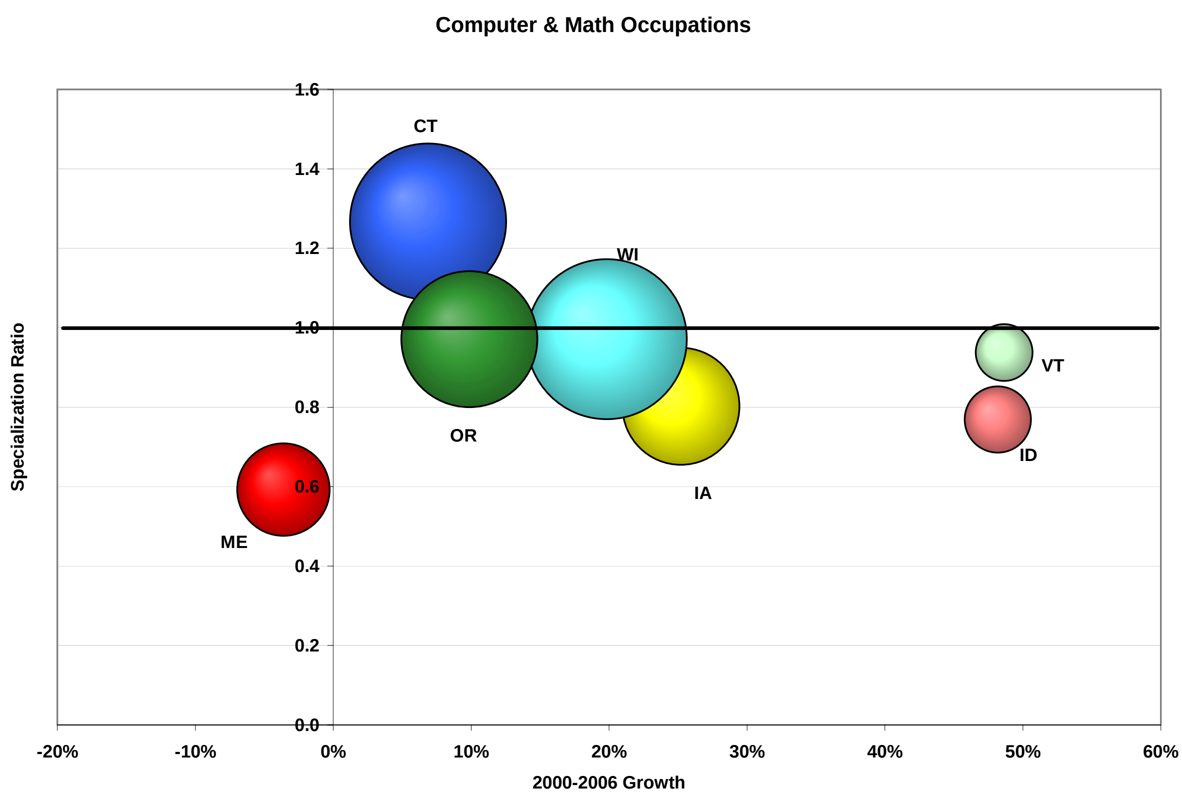
[8] The SOCs do not differentiate by subject of study, so many of the specialties in geosciences and biology should actually be considered part of the marine sciences, in which Maine is specialized relative to the U.S.

Connecticut in growth. The differences among the states other than Idaho are not as large in the sciences as in the other STEM sectors so Maine is at least somewhat comparable in this sector.[9]

On the positive side, Maine is showing some strength in occupations relative to sectors like biotechnology and environmental services (these are discussed below). But overall, either in terms of specialization in STEM or in many key occupations that have shown declines, Maine's STEM workforce appears still heavily oriented towards natural resources, and overall indicates that Maine lags the U.S. and reference states in the key knowledge and skill capacities upon which clusters can be founded.

Where will Maine get the increased workforce it will need as a foundation for technology innovation and cluster growth? Clearly one source will be national and international sources. As the interviews conducted for this project indicated, Maine's technology companies are continually engaged in recruiting workers outside of Maine, particularly those at the most advanced levels of researchers and engineers. The other source is from within the state, which raises the question of how successful Maine's institutions of higher education are in supplying the STEM workforce.

Figure 14 Computer & Math Occupations: Maine and Reference States



[9] The very high specialization of sciences in Idaho is due primarily to the Idaho National Laboratory, the descendent of the nuclear reactor research center that has been operating in Idaho since 1949. The Idaho National Laboratory employs over 3,500, and is operated by Battelle for the Department of Energy.

Figure 15 Engineering and Technical Occupations: Maine and Reference States

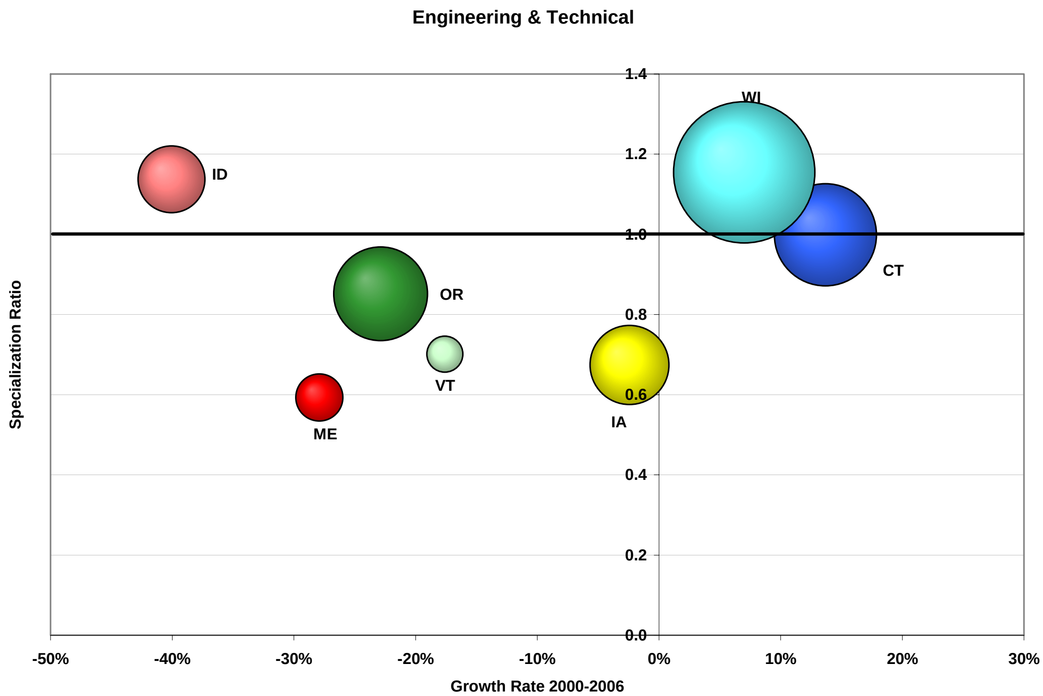
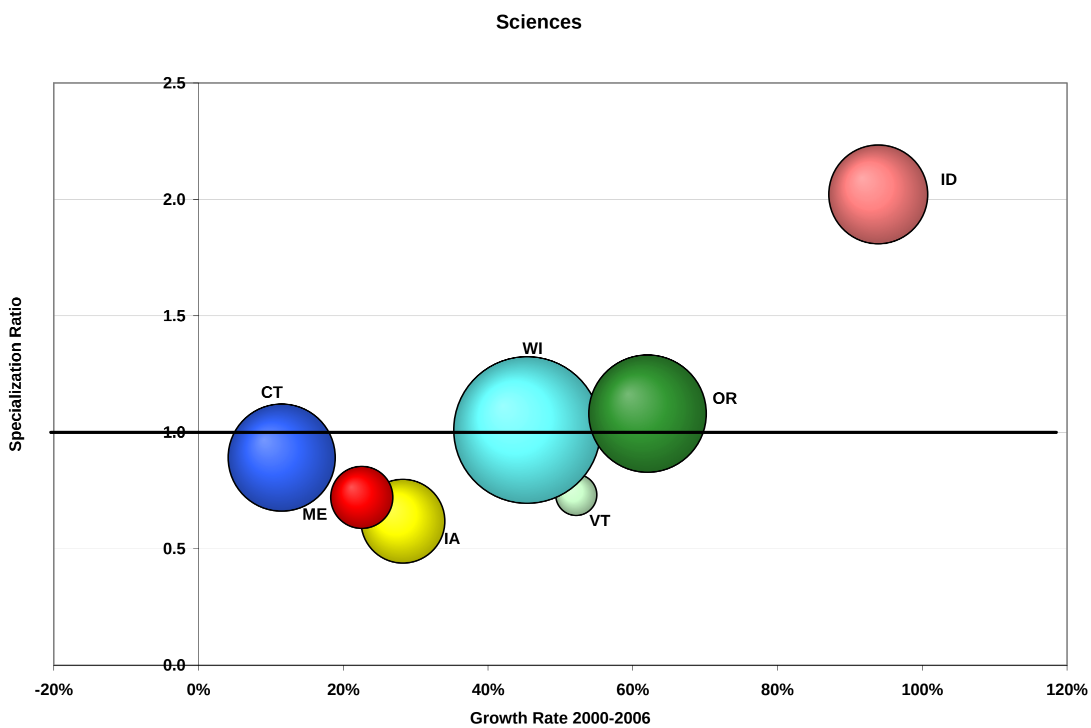


Figure 16 Scientific Occupations: Maine and Reference States



4.2 Educating the STEM Workforce in Maine

Maine's STEM workforce is examined in the following tables. This analysis is based on the Integrated Post-Secondary Education Data System (IPEDS) maintained by the National Center for Education Statistics of the U.S. Department of Education.[10] The IPEDS collects reports from virtually all institutions of higher education in the U.S. on a wide variety of dimensions of higher education. For purposes of this analysis, data on the majors of associates' and bachelor's degree recipients and on the fields of study for post-graduate degrees in 1996 and 2006 are examined. Table 12 shows data for STEM-related majors for 1996-2006, broken down between men and women.

Table 13 shows the fields of study from the IPEDS data used to define the STEM classification for this analysis. The IPEDS data do not map perfectly to the Department of Labor OES data used in the previous occupational analysis; but there are clear similarities.

The data show an overall drop in the number of degrees granted over this decade. This is partly a matter of a change in data collection methods and partly a matter of an important overall trend in higher education. The change in data collection methods occurred in 2006 when the IPEDS reporting system permitted institutions to report two majors, whereas in 1996 only one major per student was recorded. This analysis compares the major reported in 1996 with the primary major in 2006. Students with a second major are excluded from the comparison. The larger issue is that over this decade, the length of time it takes to receive a degree, graduate or undergraduate, has substantially lengthened. Enrollments in higher education have risen, but degrees granted each year have declined as students take longer to complete their education. The reasons for this are complex, and it is a pattern that is observed throughout most of the U.S. not just in Maine.

		1996	2006	Change 1996-2006
STEM Majors	Men	1,072	1,071	-0.1%
	Women	416	528	26.9%
	Total	1,488	1,599	7.5%
Non STEM	Men	6,188	3,219	-48.0%
	Women	10,084	6,050	-40.0%
	Total	16,272	9,269	-43.0%
Total	Men	7,260	4,290	-40.9%
	Women	10,500	6,578	-37.4%
	Total	17,760	10,868	-38.8%

Table 12 STEM and non-STEM degrees in Maine 1996-2006

Table 12 shows some interesting trends. In Maine, those with fields of study in the STEM areas rose from 8.4% of degrees in 1996 to 14.7% in 2006. STEM majors actually increased overall, compared with the large drops in other degree types, and it was women who were responsible for all of the increase. The number of men with STEM-related degrees was virtually unchanged over the decade. While men still outnumber women almost two to one in the STEM fields of study, the larger

[10] See http://nces.ed.gov/ipeds/.

portion of women in higher education (women received 60% of degrees in both years) has been reflected in the STEM fields of study.

Natural Resources & Conservation
Computer & Information Sciences
Engineering
Engineering technologies/ technicians
Biological/ Biomedical
Mathematics/Statistics
Physical Sciences
Precision Production

Table 13 STEM Fields of Study in IPEDS data

Additional details on the degrees in the STEM fields are provided in Table 14. Of the 8 degree types, six showed overall growth in degrees granted. The two that declined were the physical sciences and "precision production," a field of study that encompasses a variety of technical fields usually taught at the community colleges. This latter field showed by far the largest loss, dropping by half. This undoubtedly reflects the overall state of job opportunities in manufacturing occupations during this period.

The largest growth was in computer and information sciences, which comprised 30% of the growth in STEM degrees. This is interesting given the data that jobs in these fields actually decreased in Maine from 2001-2006. The second largest growth area was biological/biomedical sciences with 27% of the growth in degrees; this does match the growth in job demand in this area. The third largest growth in degrees was in natural resources and conservation. Degree holders in these fields would have found expanding job markets in occupations related to environmental management, but shrinking job markets in more traditional resource management fields.

The growth of the number of women in the STEM fields shows up in most areas. The number of women increased substantially faster than men in math and statistics, biological/biomedical, natural resources and conservation, and engineering technologies/technicians. However, men held a clear lead in the number of computer and information sciences degrees.

The source of STEM-degree holders is examined in Table 15. In this table the three public higher education systems (including Maine Maritime Academy) are shown, along with the private schools (Colby, Bates, Bowdoin, the University of New England, Husson, Thomas, St. Josephs, Andover, and College of the Atlantic). In 2006, the University of Maine System was the largest granter of STEM-related degrees, accounting for just under half (49%) of all these degrees. The private higher education institutions were second, with about 29% of all degrees. Over 1996-2006, STEM-related degrees grew fastest at the private institutions, followed by the University of Maine System and the Community Colleges. STEM degrees declined somewhat at Maine Maritime Academy, but this is consistent with an overall decline in the number of degrees at that institution.

	1996			2006			Change 1996-2006		
	Men	Women	Total	Men	Women	Total	Men	Women	Total
Natural Resources & Conservation	140	51	191	137	94	231	-2.1%	84.3%	20.9%

Computer & Information Sciences	51	12	63	99	21	120	94.1%	75.0%	90.5%
Engineering	257	44	301	266	45	311	3.5%	2.3%	3.3%
Engineering technologies/ technicians	255	22	277	270	33	303	5.9%	50.0%	9.4%
Biological/ Biomedical	165	183	348	152	247	399	-7.9%	35.0%	14.7%
Mathematics/ Statistics	47	18	65	40	32	72	-14.9%	77.8%	10.8%
Physical Sciences	91	46	137	72	57	129	-20.9%	23.9%	-5.8%
Precision Production	58	8	66	30	3	33	-48.3%	-62.5%	-50.0%

Table 14 STEM Fields of Degree in Maine 1996-2006

		1996	2006	Change 1996-2006
Maine Community College System	Non-STEM	1,727	1,330	-23.0%
	STEM	235	252	7.2%
	Total	1,962	1,582	-19.4%
Maine Maritime Academy	Non-STEM	215	82	-61.9%
	STEM	109	102	-6.4%
	Total	324	184	-43.2%
Private Higher Ed	Non-STEM	6,129	3,214	-47.6%
	STEM	419	462	10.3%
	Total	6,548	3,676	-43.9%
University of Maine System	Non-STEM	8,201	4,643	-43.4%
	STEM	725	783	8.0%
	Total	8,926	5,426	-39.2%

Table 15 STEM Degrees by Higher Education System in Maine

		1996			2006			Change 1996-2006		
		Men	Women	Total	Men	Women	Total	Men	Women	Total
Maine Community College System	CMCC	77	18	95	47	5	52	-39%	-72%	-45%
	EMCC	41	1	42	63	2	65	54%	100%	55%
	KVCC	7	2	9	22	4	26	214%	100%	189%
	NMCC	24	1	25	12	3	15	-50%	200%	-40%
	SMCC	51	12	63	71	18	89	39%	50%	41%
	WCCC	1	0	1	1		1	0%		0%
	YCCC				4		4			

	TOTAL	201	34	235	220	32	252	9%	-6%	7%
University of Maine System	UMA	5	3	8	11	13	24	120%	333%	200%
	UMF	14	9	23	10	13	23	-29%	44%	0%
	UMFK	7	3	10	5	5	10	-29%	67%	0%
	UMM	9	13	22	8	17	25	-11%	31%	14%
	UMPI	3	2	5	2	3	5	-33%	50%	0%
	UM	414	137	551	381	171	552	-8%	25%	0%
	USM	78	28	106	101	43	144	29%	54%	36%
	TOTAL	530	195	725	518	265	783	-2%	36%	8%

Table 16 STEM Degrees in MCCS and UMS by Gender

The importance of the two larger public systems requires a more detailed analysis. This is provided in Table 16, which shows the distribution of degrees by campus within these two systems. It is clear that the University of Maine dominates the awarding of degrees in STEM fields; in 2006 UM awarded 35% of all the STEM degrees and 41% of all the degrees from bachelor's degree institutions (MMA, UMS, and privates). UM is by far the largest grantor of degrees in the STEM fields, but the overall number has not grown. The University of Southern Maine is second to UM, and did show more than a one-third growth. The other campuses of the University of Maine System barely register in terms of the number of degrees awarded, though small numbers produce some large percent changes.

USM accounted for 9% of STEM degrees in 2006, and showed a healthy growth of more than a third in the number of degrees awarded over 1996-2006. This growth was a sign of the shift at USM towards the STEM fields which was a product of state R&D investments. However, USM's contribution to STEM fields is still disproportionately small: in 2006, Colby, Bates, and Bowdoin had a little more than half the total number of students of USM yet produced more than twice as many STEM degrees. In fact, Colby, Bates, and Bowdoin account for 20% of all the STEM degrees awarded in Maine in 2006. Given the high proportion of students in these institutions who come from out-of-state and who will likely leave Maine upon graduation, their contribution to the STEM workforce will be less than their degree output rates would suggest.

The number of degrees coming from the MCCS campuses has grown overall, with most of the growth (56%) coming from Southern Maine Community College in South Portland. This represents a shift. In 1996, Central Maine Community College in Auburn accounted for the largest number of STEM degrees, but CMMC saw a decline of nearly half in STEM degrees over this decade, while SMCC grew by nearly half. As at the University of Maine System, women led the way.

It is clear that Maine has made progress in increasing the number of people emerging from the higher education systems with STEM degrees. Women, particularly in the biological and biomedical sciences and in natural resources, have been critical to this growth. The University of Maine leads the way by a significant margin in the awarding of STEM degrees, followed by the CBB colleges. The remaining question is whether the gains in STEM-related higher education in Maine increases the capacity for generating technology innovation in such a way as to increase Maine's technology based competitiveness. This is explored in Figure 17 and
Figure 18.

In Figure 17, the proportion of each degree type of STEM-related degrees in 2006 for both Maine and the U.S. is compared. For associate's degrees, Maine and the U.S. awarded about the same proportion of STEM degrees in 2006. A larger proportion of Maine's bachelor's degrees (18% v. 10% in the US) were in STEM fields, but at the masters level, Maine's proportion of STEM degrees is about half that of the U.S. A higher proportion of Maine doctorates are in STEM fields, but this is a little skewed since only one institution, the University of Maine, awards most of the doctorate degrees.

Figure 17 STEM Field Proportion of Degree Type: US and Maine 2006

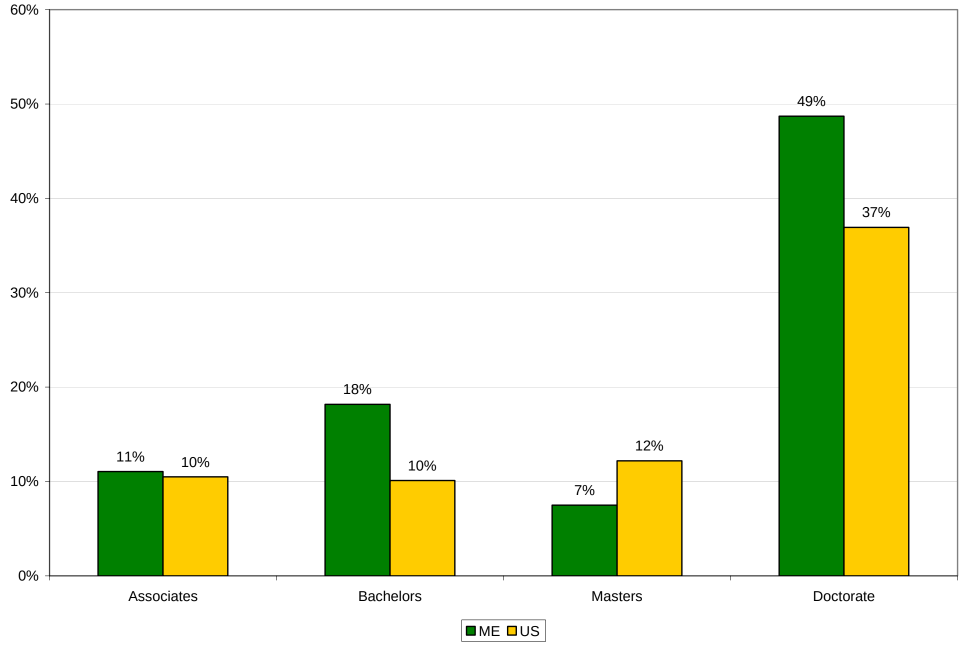


Figure 18 Degree Type as Proportion of STEM Degrees US and Maine 2006

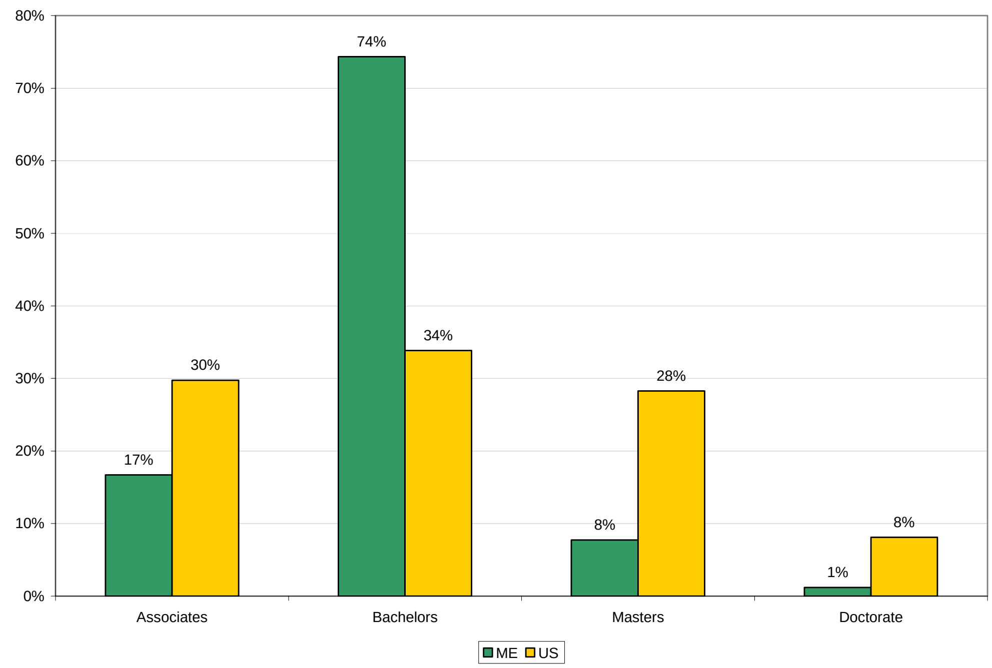


Figure 18 shows the proportion of all STEM degrees at each level in Maine and the U.S. There are significant differences between Maine and the U.S. Maine's STEM degrees are much more heavily concentrated at the bachelor's degree level than in the U.S. The bachelor's degree level accounts for more than twice the proportion in Maine as in the U.S., with the consequence that the other levels account for smaller proportions. Associate's degrees are half the percentage of STEM degrees in Maine, while the proportions are even smaller at the post graduate degree level. This data is consistent with the comments of many interviewees that the workforce with technical degrees is relatively abundant at the bachelor's level and relatively scarce at the graduate degree level.

This comparative analysis suggests that, except at the bachelor's degree level, Maine's higher education systems are lagging behind the rest of the U.S. in the production of STEM-related post-secondary degrees. This is particularly the case at the graduate level, where the key training for developing innovations takes place. To what extent this lag is the result of supply problems (too few programs for post graduate or associates study) or demand (too few students wanting to go on to graduate school or to study in a STEM field at the associates level) is not known. However, the lag has serious implications for the ability of the academic research enterprise to support knowledge generation because graduate students play a far larger role in the conduct of research at the university than do undergraduates.

4.3 Summary

Overall, the occupational data shows that Maine is less specialized in the major STEM (Science, Technology, Engineering, and Mathematics) occupations than the U.S. as a whole, but there are some clear specializations in particular fields[11]. These include the following occupational groupings:

- Computer and Mathematics
  - Mathematicians
  - Database Administrators
  - Systems Software Engineers
  - Research Computer Scientists

- Engineering and Technicians
  - Electro-mechanical Technicians
  - Marine Engineers and Naval Architects
  - Environmental Engineers
  - Chemical Engineers
  - Cartographers and Photogrammetrists

- Sciences
  - Hydrologists
  - Geoscientists
  - Environmental Scientists
  - Environmental Science and Protection Technicians
  - Foresters
  - Zoologists and Wildlife Biologists
  - Microbiologists
  - Soil and plant scientists

A summary comparison of growth trends over the period 2000-2006 in STEM occupations in Maine and the U.S. is shown in Table 17. In general, occupations in computer and mathematics fields showed decline in Maine relative to the U.S., though there were some occupations, particularly in network support and administration, where Maine outpaced the U.S. The greater decline in software engineers in Maine than in the U.S. is a disturbing sign. Maine also saw declines in other engineering fields, though in many cases these occupations were also declining in the U.S. Maine does show growth in science occupations, including several areas where Maine outpaced U.S. growth rates. Only foresters declined in Maine significantly. The size, relative concentration, and growth rates in Maine compare unfavorably with all six of the peer states chosen for reference.

[11] Specialization Ratio>1

	GROWTH IN MAINE		*DECLINE IN MAINE*	
	Maine Growth Faster than US	**Maine Growth Slower than US**	**Maine Decline US Growth**	**Maine and US Decline**
Computers & Math	Network Administrators Database Administrators Computer Support Programmers		Software Applications Engineers Systems Software Engineers Research Computer Scientists Other Computer/Math Occupations	Computer System Analysts
Engineering and Technician	Surveying and Mapping Technicians Electrical and Electronic Drafters Environmental Engineers	Civil Engineers Cartographers/ Photogrammetrists	Environmental Engineering Technicians Mechanical Engineers Industrial Engineers Electronics Engineers except computers	Electromechanical Technicians Electrical and Electronic Engineering Technicians Materials Engineers Electrical Engineers Chemical Engineers
Sciences	Chemical Technicians Environmental Scientists and Specialists Chemists Microbiologists	Environmental Science and Protection Technicians Geoscientists Physicists Zoologists and Wildlife Biologists Biochemists and Biophysicists	Foresters	

Table 17 STEM Occupational Growth Summary

Maine's higher education institutions have increased their output of degrees in STEM-related degree fields over 1996-2006, with women leading the growth. Growth has been particularly strong in the biological/biomedical and natural resources/conservation fields. The University of Maine is responsible for a significant majority of STEM-related degrees, with the private liberal arts colleges second. Overall, Maine produces a much higher proportion of bachelor's degrees in STEM fields than the U.S. and a much lower proportion of graduate degrees, which raises questions about the ability of educational institutions to sustain a high level of innovative research activity.

5. Biotechnology

5.1 Analysis

"Biotechnology" covers a great variety of research and innovation. The term originally referred to the possible applications derived from the manipulation of genes in order to shift biological functions in organisms. In this sense, the field of biotechnology is less than forty years old, dating back to the invention of reading the code of the four proteins that make up the double helical DNA molecule in the 1970's. Other inventions of the 1970's and 1980's greatly speeded the "reading" process and also permitted bits of DNA to be "snipped" from one organism and placed in another organism, creating new transgenic functions such as disease resistance. Together these genetics-based activities fall under a general heading of "genomics."

Another branch of biotechnology involves the manipulation of protein molecules, the basic chemical building block of many living organisms. This field of research, which has become known as proteomics, is directed at finding ways to beneficially change living organisms to cure disease or enhance growth. Together, genomics and proteomics are finding applications in three broad fields.

The first is agriculture, where manipulation of genetic material has been increasingly, and controversially, used to create crops that are disease or insect resistant or that have other desirable properties that cannot easily be obtained through more traditional cross-breeding techniques. Some applications of biotechnologies in this sense are also applied to aquaculture.

The second is the emerging field of industrial biotechnology. This incorporates a wide range of processes in which biological inputs are manipulated at the genetic or protein level to yield the raw materials such as enzymes for a variety of products. These products may be used as fuels to replace petroleum, or as biodegradable plastics and other materials. This field of research is significantly expanding, and is poised to have potentially large impacts in a variety of markets.

The third area is medical, in which developments in genomics have allowed a much more detailed understanding of the genetic basis of disease and raised the possibility of developing medicines and treatments that are specifically targeted to an individual's genetic characteristics, thus potentially greatly enhancing the efficacy of medical treatments while lowering the dangers of adverse side effects.

However, the term biotechnology has become broadened to include a number of different activities within the general field of bio-medical research and the development of new therapies for human health. Within the general area of medical applications, "biotechnology" is now used to include the more traditional pharmaceutical industries, which are based more on biochemistry than genetics. The term also incorporates the biomedical devices industry ranging from prosthetics and implants to surgical instruments and the increasingly complex technologies of monitoring and diagnosis.

In Maine, the biotechnology sector is primarily concerned with applications in the bio-medical field as opposed to agriculture. As noted in Chapter 3, there have been very few patents coming from Maine in the "plant patent" category. The term "biotechnology" is also sometimes applied to research in a great deal of traditional agricultural research based on genetics and chemistry. Biotechnology is also beginning to be applied in the aquaculture sector, though this is still at rather small scale. For example, newer developments in such fields as proteomics (the development of new protein-based applications) are being used in aquaculture, as exemplified by the work with calcium-ion receptor proteins being developed by MariCal, a firm in Portland.

Industrial biotechnology is an emerging field in Maine, with efforts underway to research bio-fuels from wood (cellulosic ethanol) and bio-plastics from potatoes. More discussion of these areas may be found in Chapter 8 below on forest products and agriculture.

The focus in this chapter is on three subsectors: life sciences R&D, medical equipment/supplies, and drugs/pharmaceuticals. Of these three subsectors, the most critical in Maine are life sciences R&D and drugs/pharmaceuticals. The medical equipment industry in Maine, though of modest size, consists of a variety of industries largely serving the local healthcare market with products such as orthotics, dentures, etc. Some innovation and research may take place within these industries in Maine, but the scale is currently very small. This subsector has been an important contributor to the overall growth of employment in biotechnology in Maine, but it largely as part of overall growth in healthcare services.

It is in the other two subsectors that Maine's biotechnology sector has concentrated its efforts at innovation; and here, there is a substantial record of success. A major part of that success has been in the life sciences R&D industry, where Maine has established significant strength in genetics research at The Jackson Laboratory and in other areas of biomedical research at the Maine Medical Center Research Institute, Foundation for Blood Research, and Mount Desert Island Biological Laboratory. Another institution, the Maine Institute for Human Genetics and Health, has been established and is in the early stages of becoming organized. These organizations have shown substantial growth in the last decade, particularly The Jackson Laboratory. To understand the evolving role of these subsectors, it is necessary to place what Maine does in the context of the larger evolution of the human-health-related biotechnology industries.

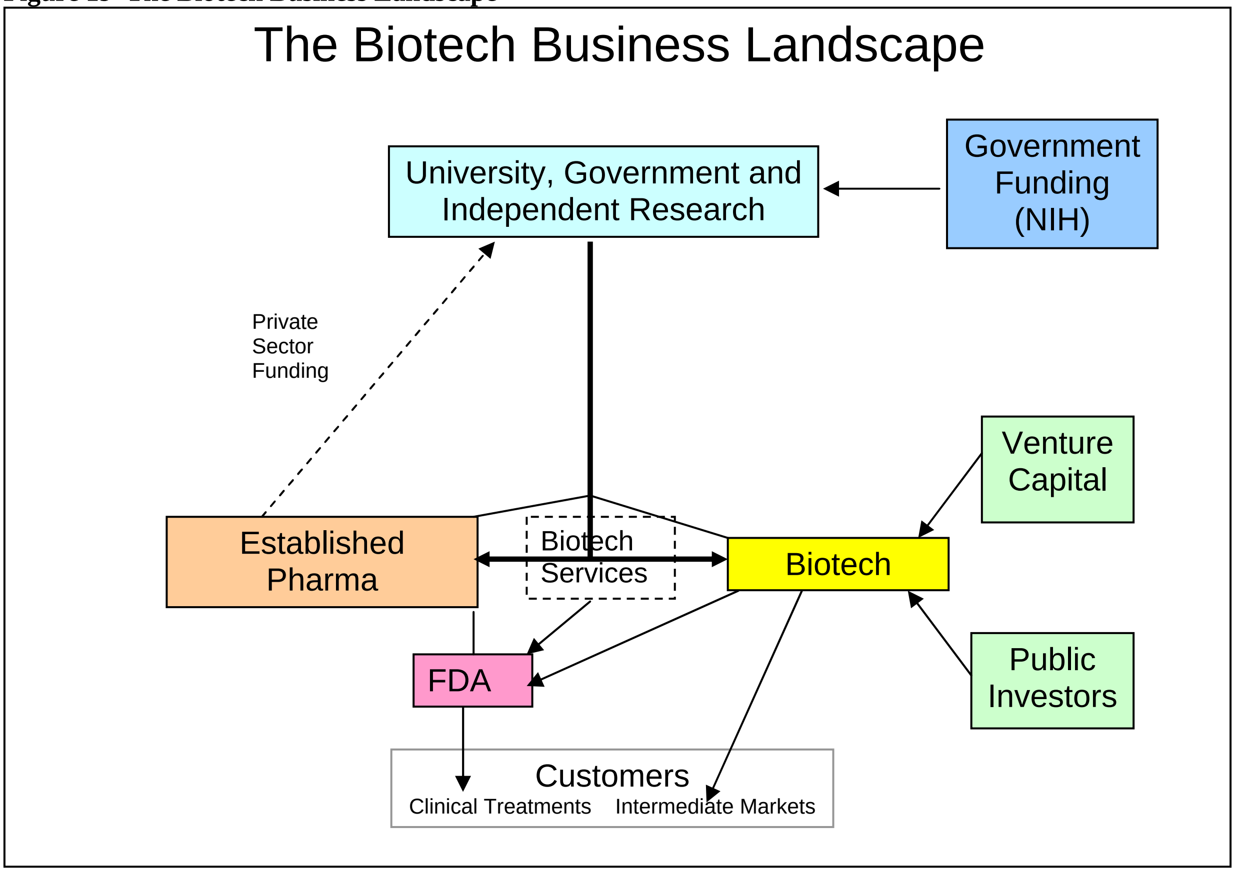
The Human Health Biotechnology Industries

The various industries seeking to develop new products for human health grouped as "biotechnology" are a cumulative evolution from the pharmaceutical industry, which has been in existence for more than a century. The key force in the evolution has been the increasing knowledge of genetics, which has the potential to fundamentally alter the development of new treatments for diseases. The changes brought about by the genetics revolution made it possible to develop much more effective treatments, but has also vastly expanded the risks and uncertainties associated with the development of new treatments. In the process of dramatically changing the science, it also changed the institutional landscape in which biomedical research takes place. The evolution of biotech clusters has been shaped by this interaction between the nature of the science and the institutions.

In his recent study of biotechnology, Gary Pisano at the Harvard Business School argues that the most important factor shaping the science of the biotech business is the "vastness and complexity of the underlying science" (Pisano 2006). Developments in genetics and biochemistry have greatly increased the number of "targets" that drugs can be aimed at to deal with disease, but at the same time increased the number of ways in which a drug can fail. This greatly increases the financial risks associated with R&D in this area, but also increases the potential rewards. The result requires a much more complex way of organizing the relationship between science and commerce than existed forty years ago. A simplified view of these relationships is shown in Figure 19..

The most salient feature of the contemporary biotech landscape are the three major types of institutions where research and development are performed. Research institutions, including universities, independent research laboratories such as The Jackson Laboratory or Maine Medical Center Research Institute, and government laboratories all play a much bigger role in generating the basic science on which much of the rest of the sector depends. This much larger role has been fueled by a huge increase in public funding of biomedical research, primarily from the National Institutes of Health, but also increasingly from state governments, as exemplified by proposals for large increases in stem cell related research in Massachusetts and California.

Figure 19 The Biotech Business Landscape



The key innovation in the landscape is the biotech firm, which has become a major source of drug products developed outside the large pharmaceutical companies (Pisano 2006). The first such firm was Genentech, founded in Boston in 1976. The biotech firm takes on many different forms and performs many different functions. The prototypical biotech firm is, like Genentech, a spin off from university-based researchers which has the principal purpose of taking an idea originated in basic research at the university (or other research institution) and then undertaken the additional research and development work needed to bring the product to market. This translational function takes on many forms. Some biotech companies only license their technologies, some conduct substantial research, some vertically integrate forward to carry drugs through the clinical trials phase or even to the manufacturing stage.

A growing trend is for biotech companies to enter into alliances or collaborations with the large multiple-purpose international pharmaceutical companies such Merck or Pharmacia. These large pharmaceutical companies, which once undertook almost all of their research themselves, are now themselves complex mixtures of in-house R&D, production, and marketing. They are nodes in complex networks of funding, research, intellectual property management, and distribution.

At the interface among these three legs of the biotech R&D complex is an emerging industry of what might be termed biotechnology services. These services include the expertise needed to manage the complex intellectual property issues involved in biotechnology, particularly the sharing of the monetary gains from innovation among the many partners who may be involved in a particular product. It also includes highly specialized companies who will manage the process of conducting clinical trials for biotech companies who are not allied with large pharmaceutical companies in a particular drug development project. Biotech service companies are not necessarily specialized firms. Some firms may do development work on their own research projects and simultaneously provide other companies with marketing or other services.

Also part of this complex landscape are flows of capital. Research is predominantly funded by the public sector, but pharmaceutical companies may also fund some of the activities at research institutions. The biotech sector itself must attract capital if the start up firms spun off from research institutions are to carry out their functions. The ideal path is to attract investments from the venture capital community to bring a firm to the point where it can attract further investments from public markets. The initial public offering (IPO) of stock is the point at which the venture capital investor is ideally paid for their investment.

Broadly speaking, there are two types of markets into which the results of biotech R&D feed. The first is the market for therapeutic uses in clinical setting such as prescription drugs. These products must proceed through the regulatory approval process of the Food and Drug Administration (FDA), which greatly increases the time and cost involved with bringing a product to market. The other route is to what may be termed "intermediate" goods. These include a variety of products that are not used directly in disease treatment, but may be used for such purposes as diagnosis or monitoring of biological conditions. Also in this category are research tools which may be used to improve or expand the research process itself.

The most salient feature of this industrial landscape is the great flexibility it provides to adapt different organizational forms and arrangements to manage the great uncertainties associated with biotechnology research. Again, the key is the biotech firm. Pisano argues that the modern biotech firm in all its variety and flexibility is in fact a new type of business. Rather than a business which uses science, it is a firm whose business *is* science. The novelty is the high levels of uncertainties and risks associated with science have traditionally made science much more characterized as a public good than a private good, more suitable for funding by the public or nonprofit sector than the private sector. Yet it is precisely this characteristic that the biotech firms seeks to reverse by finding ways to, as Pisano puts it, "monetize the intellectual property" generated through research.

The nature of this landscape has important implications for efforts to base economic development in the biotech sector. The first is that the functioning of the institutions in this landscape depends to a great deal on geographic proximity in order to facilitate close integration of all the players. The field is dominated by information asymmetries among all the players. That is, key information is concentrated in the hands of a very few people, but the information needed for success is so complex that many people must be involved. A major way that all involved can manage risks is to work with people and organizations with which they have worked in the past and with whom they have constant interaction.

Proximity is also a key to the sharing of information among players in order to learn how to do biotechnology better. This learning takes place in a typical cluster pattern by exchange of people between organizations. But there is another feature to the biotechnology which substantially enhances the desirability of proximity for easy sharing of information. Pisano terms this "integrality", the need to integrate knowledge of what is happening across the entire system of research, development, and therapeutic applications. Integrality greatly increases the need for interdisciplinary science in which experts in genetics, biochemistry, information technology, and medicine work together to bring products to market.

Biotechnology development tends to occur in relatively compact geographic spaces in order to maximize essential connections and minimize communications difficulties. One commentator estimated that 25% of all biotechnology activity in the U.S. was taking place within 35 miles of a campus of the University of California system. An equal proportion probably takes place within a similar distance from Harvard Square. Half the founders of biotech firms in the Boston area came from universities (primarily Harvard and MIT) and most are involved in both their company and the university (Pisano 2006).

Biotechnology has also clearly been a major attraction for economic development efforts over the past decade, as there have been many studies which have played up the growth potential of the industry. Clearly, there has been enormous growth in biotechnology as measured by employment, but oddly, public biotechnology firms have also been, on average, relatively bad investments. The vast majority of biotech firms have never achieved positive cash flows, and two firms, Amgen and Genentech, have accounted for more than half of all the cash generated by the publicly-traded companies in the industry (Pisano 2006). This is not to suggest that biotech firms have not been profitable–only that the major route to profits is more likely to be to remain privately held and earn income through licensing or other alliance arrangements, or to sell to a public firm (often an established pharmaceutical firm).

Having sketched a rough picture of the complex biotechnology industry as it has developed in the biomedical field, it is now possible to survey Maine's position in this landscape. Like the overall industry, Maine is undergoing rapid changes which nonetheless suggest ways in which Maine can build.

Research

The analysis (in Chapter 3) of research concentrations in Maine identifies seven areas of specialization within Maine's research capacity related to biomedicine: genetics and genomics; bone and hematopoiesis (blood generation); cancer and oncology; cardiovascular research; immunology and infectious diseases; and surgery. All together, the biomedical research records comprise nearly one third of the measures of research productivity in the Battelle analysis, with genetics/genomics the single largest category with 12% of the records. The analysis also indicates that biotechnology is the only one of Maine's seven technology sectors with high levels of strength across all measures (grants, publications, and patents).

This analysis indicates that biomedical science research in Maine is a significant enterprise, and is also a highly diverse one in terms of the different subjects under research. However, it is also highly concentrated. A significant majority of the grants, publications, and patents is associated with The Jackson Laboratory. While other research institutions are gaining momentum in research productivity, Jackson maintains a significant dominance. This is obviously the case with the genetics/genomics category, but it also includes research in cancer, blood, diabetes, and other specific diseases.

Occupational and educational data also indicate emerging strengths in biological and biomedical research. Occupational data show Maine has a relative specialty in microbiologists, and this occupational specialty grew by 60% from 2000-2005, compared with a 1% decline in the U.S. One third of the growth in Science, Technology, Engineering and Mathematics (STEM) related degrees between 1996 and 2006 was accounted for by degrees in biological/biomedical fields, though the growth was not large in absolute terms (see Chapter 4).

Analysis of the industries related to biotechnology (see Section 5.3 below) shows significant presence and growth for life sciences research employment (again dominated by The Jackson Laboratory), and drugs and pharmaceuticals in Maine. This subsector in Maine is a mixture of firms which do research to serve markets for diagnostic materials and equipment and also directly for pharmaceutical product development. Only a relatively small portion of the research activity is directly related to drug development. Rather, Maine has become more specialized in the general field of diagnostic and antibody development used not to treat, but to detect and monitor diseases and other abnormal conditions.

The diagnostics field is also the area where Maine's biotechnology sector is most clearly involved in commercialization of research. Three of the five biotech high-growth companies identified by the University of North Carolina in a study for DECD were in this field, and fourteen of the thirty-one companies receiving MTI funds (whose grants closed by June 30, 2006) were in the diagnostics/antibodies area. There are several reasons for this specialization in this field:

Many of the firms and individuals involved in this field were associated with Ventrex, a firm established in Portland in the 1970's to produce monoclonal antibodies for diagnostic purposes. Ventrex was part of the first wave of biotechnology companies; it was eventually sold and its operations moved to California, but many of the people remained behind to start their own companies. As these companies grew, more spinoffs occurred. Research organizations such as the Foundation for Blood Research and researchers at both USM and UM aided the development of technologies in this area.

Another key factor in the development of diagnostics and related products as a field of specialization is that diagnostic-related products have potentially large markets, but do not receive the same level of regulatory supervision that is applied to therapeutic drugs. This dramatically lowers the cost of bringing these products to market, which means significantly lower barriers to entry in this field. One interviewee noted that the concentration in this field may be a natural starting place for the development of biotechnology industries within a region because of these lowered barriers to entry.

These two areas, genetics and diagnostics, are perhaps the clearest strengths in Maine's biotechnology sector. They are different in important ways aside from the massiveness of The Jackson Laboratory in comparison with the numerous smaller enterprises engaged in the diagnostics field. As noted, diagnostics-related research and products is the area with the greatest level of commercial success in Maine biotechnology. This includes IDEXX, the largest commercial biotechnology firm in Maine, which utilizes much of the same knowledge and skills base of the diagnostics sector to develop products for veterinary markets. IDEXX is the second largest recipient of patents in Maine.

The Jackson Laboratory's principal research in genetics and genomics is primarily in areas of basic science that is some distance from the development of commercial applications in terms of therapeutic products. It is noteworthy, however, that The Jackson Laboratory has seen its first commercial spin off; a firm called Bar Harbor Biotechnology opened its doors in 2007 to market a set of software tools to improve the speed and accuracy of gene expression analysis, a key step in the application of genetic theory to the development of therapeutic and other uses. In this way, both The Jackson Laboratory and the diagnostics are further establishing Maine's position in the "intermediate products" portion of the biotechnology market.

The world class strength of The Jackson Laboratory and the emerging strength in diagnostics may just be the beginning of a competitive biotechnology sector in Maine. A number of recent developments have laid the foundation for perhaps significant development in this area in the future, including:

- The University of Maine, in collaboration with USM, UNE, and four other medical research organizations has created a Graduate School of Biomedical Sciences to produce doctoral researchers in the fields of molecular and cellular biology, neuroscience, and biomedical engineering, with an interdisciplinary doctorate in functional genomics. GSBS has the potential to fill some of the critical needs for researchers in the future.

- Maine Medical Center Research Institute already has two centers of biomedical research excellence (COBRE's) in vascular biology and in stem & progenitor cell biology. The Institute is seeking to significantly expand its research program to 25 principal investigators. Already participating in the GSBS program, MMCRI will also be linked to the development of a medical school at Maine Medical Center itself. MMC is developing a medical school in collaboration with Tufts University to take on a more direct pre-clinical training role for MDs. This would be Maine's second medical school along with that of the University of New England.

- As MMC is expanding towards more education, the University of New England is both expanding its educational programs and its research activities. The University is adding a school of pharmacy and is also raising money for a new research facility. UNE is also developing spin off activity. A biotech firm, Aiko Pharmaceuticals, has been established to develop on pharmaceutical treatments for opiate addictions.

- A new research institute, the Maine Institute for Human Genetics and Health, has been established with a home base at Eastern Maine Health Systems and operating in collaboration with The Jackson Laboratory and the University of Maine. The Institute will focus on new "core" concepts to research areas such as cancer and neurogenetics and regenerative medicine. This institute will work on developing applications of genetics research that are closer to therapeutic markets than is usually the case at Jackson.

These developments on top of an already impressive growth in biotechnology research and emerging strengths in commercialization may presage significant growth in this sector in the coming years that builds on current strengths and moves into new scientific areas and new markets. If this happens, Maine biotechnology will look increasingly like the general map of the biotechnology industry discussed above. But one should not in any way underestimate the challenges that Maine faces in developing competitively successful biotechnology clusters. These challenges, as identified by those interviewed for this project, may be grouped in six categories: scale, distance, workforce, funding, infrastructure, and services.

A constant theme expressed by interviewees was that Maine's biotechnology is, apart from The Jackson Laboratory, simply too small scale for long term competitive success. There will undoubtedly be successful firms, and even success within narrowly defined industries, but the type of sustainable success that the biotech industry is capable of requires operations at a much bigger scale. Primarily, this is seen as greatly increasing the volume of research: "feeding the pipeline" as one person put it. Much will depend on sustained success at The Jackson Laboratory and significant growth at the other research institutions, including the University of Maine, University of Southern Maine, and UNE. Beyond this, there must be an increase in the density and size of biotech firms, for they are the key to long-term growth in commercial markets, and the development of biotech services to support both.

One issue that was raised in interviews was whether it would be necessary for Maine to attract a large operation from one of the major biotech companies to Maine as a key part of building to scale. Some interviewees mentioned Rhode Island's attraction of a $1.5 billion manufacturing center for Amgen to West Greenwich as an example of what Maine should seek. Clearly such a development would be desirable, but it will likely be difficult since such expansions are relatively rare.

Maine is attempting to deal with the scale issue by networking universities, research institutions, and private-sector firms to create virtual scale. In one way, this is entirely consistent with the overall framework within which the biotech sector operates. Even in its major centers, biotechnology is developed as a network of public, non-profit, and private organizations. However, all networks require significant efforts on all parties to overcome organizational frictions that inevitably arise and soak up the time and energy of participants. The networks behind the Graduate School of Biomedical Sciences, the Maine Biomedical Research Coalition, and the Maine Institute for Human Genetics and Health indicate very high levels of commitment and energy, levels which will have to be sustained for an indefinite future. Maine must deal with these frictions plus the handicap of distance.

The biotechnology landscape sketched above is spread out across the world, but concentrated in only a few relatively small geographic areas. Distance between the elements of the sector does matter for a variety of reasons. While Maine is building significant capacity in biotechnology, it must contend with significant issues of distance in a triangle stretching from Bar Harbor to the Bangor region to the Portland area.

There is no doubt that technology helps overcome some of the difficulties of distance. One could not imagine there being any chance for Maine to achieve effective collaborations across the distances required without the Internet, video conferencing, cell phones, and a willingness to routinely drive long distances that seems to come with a Maine driver's license. But the telecommunications coverage and capacity is still weak in places; high-speed internet has yet to come to much of Mt. Desert Island, though The Jackson Laboratory has state-of-the-art communications.

Another aspect of the distance issue is the relationship between Maine biotechnology and the rest of New England. Taken together, New England is, along with California, at the center of global biotechnology. But Massachusetts and greater Boston (the region within the I-495 arc plus Worcester) dominate New England. The concentration of biotechnology in this area is so great that the region has given itself the trademarked name of Genetown.

The relationship between Maine and the Massachusetts biotechnology center is difficult to discern. Some interviewees argued that Maine, particularly The Jackson Laboratory, is already part of the Boston biotech center, while others argued that we are still not seen as part of that community, or at best as a rather remote set of activities on the periphery. There have been several efforts underway, of which MMCRI and others have been a part, to forge alliances across what might be called the "non-Boston" New England biotechnology centers such as Brown, Dartmouth, the University of Massachusetts Medical School and the University of Vermont. Such ideas for "alliances of the periphery" suggest that it is difficult to integrate with the Boston center.

Figure 20 Genetown

Biotechnology thrives with large scale and small distances. Maine currently offers small scale and large distances. It is not an exaggeration to say that successful growth of biotechnology in Maine will arise as much or more from innovative approaches to overcoming these disadvantages as to any specific innovations in science or products. Maine will also have to become more a part of the New England biotechnology community, whether in alliance with partners outside or inside greater Boston, or, most likely, both.

The evolution of the biotechnology industry in New England appears to be very different from the evolution of the computer and electronics industries across the region from the 1960's to the 1980's. In the case of electronics, technologies whose theoretical and basic research foundations were developed near MIT and Harvard eventually spread through much of the region as the new technologies were transformed into the electronics and computer manufacturing industries. Computer makers such as Data General, Wang, and Digital spread manufacturing facilities across Massachusetts, then into New Hampshire and to a lesser extent into Maine and Rhode Island. The result was a robust electronics/computer industry across the region by the 1980's. The replacement of the minicomputers in which New England specialized with the microcomputers that came out of California in the 1980's and 1990's, combined with the increased transfer of manufacturing to other countries, resulted in a significant drop in the electronics industry in New England and Maine (see Chapter 11).

Biotechnology is not following the same pattern. Large-scale manufacturing of pharmaceutical products, which requires very complex high technology processes, is not taking place to a great extent in New England even though most of the research and development is taking place in Massachusetts. There is some large-scale manufacturing (Amgen has recently opened a major facility in East Greenwich, Rhode Island) and a number of small-batch manufacturing facilities spread throughout the region, including Maine. But the regional evolution of biotechnology is proceeding in new ways compared with the last major technology industry in Maine.

A recent study by the Donahue Institute at the University of Massachusetts of the patterns of growth of the major pharmaceutical and biotechnology companies in Massachusetts identifies found that Massachusetts itself was not a prime location for manufacturing largely because of concerns about the cost of living, land costs, and the responsiveness of government in the Commonwealth to the needs of the industry (Nakajima and Loveland 2007). This would suggest that Maine might have an opportunity to attract some of this activity, increasing the range of activities within the state. Interviews conducted in the UMASS Donahue Institute study suggested the industry was more likely to look at places like North Carolina, Ireland, or Singapore, so Maine would have serious competition in attracting this activity.

Aside from manufacturing, it is clear that Maine's biotechnology industries will have to find a way to become part of expanding Massachusetts biotechnology networks. Massachusetts and California are the two major centers for biotechnology in the United States and two of the largest in the world. It would seem very unlikely that Maine can flourish as the home of sustainable clusters in biotechnology without integrating with Massachusetts. The plus side of the economic geography of biotechnology is that it is heavily reliant on networks of research and development organizations in which Maine's institutions can play an important and growing role.

Having an adequate workforce in the biological/biomedical fields will be critical to Maine playing an important role. The occupational analysis shows Maine more or less holding its own in the biochemical and biophysical sectors of the workforce. Maine is slightly less specialized in these two fields than the U.S., but the difference is not large (specialization ratio=.95). Growth in these occupations has also been comparable to the U.S.

Several different stories are told about the adequacy of the workforce within Maine. Interviewees indicated that acquiring workers with technical skills at the associates or bachelors degree levels was not particularly difficult. The supply was not abundant, but was usually adequate. Maine colleges and community colleges seem to be producing good quantities of skilled workers in these general areas, though there are undoubtedly episodic cases of shortages and lengthy recruiting times, particularly for highly-specialized skills.

However, there is significant concern about the availability of higher skilled workers at the masters and doctoral level. While efforts such as the GSBS will improve this situation, it will also take several years for the improvements to occur. Maine will likely to continue to rely primarily on recruiting the most advanced researchers (i.e., those who really drive research enterprise and shape the course for the entire sector) from outside the state. Maine has all of its traditional advantages in high quality of life, but also all the disadvantages of a thin labor market in which recruits will inevitably ask themselves whether they want to come to a place with few other opportunities available.

Given all of the efforts elsewhere in the United States and the world to encourage biotechnology as a growth leader, it is likely that competition for the top talent will only intensify greatly. While Maine has its advantages in attracting talent, it simply cannot be assumed that quality of life will always win out. A robust future for biotechnology in Maine must increasingly rely on self-supply of the advanced labor force, and that means continued expansion of the educational infrastructure and services needed to create that supply.

Growth in biotechnology in Maine has come about through the creative energy of a great many people over the past fifteen years, but that growth has been fueled by deliberate public policy decisions. Most obvious within the state has been the increased funding for research and development. Over $82 million of state funds have been invested in the nonprofit research centers in the state over the past decade.

However, the real driver of growth has been federal funding, particularly from the National Institutes of Health. NIH currently spends over $28 billion on research per year, distributed primarily through 50,000 grants. Over the same decade that Maine has greatly expanded its support for R&D, the NIH budget has almost tripled from $11.3 billion in 1995 to $28 billion in 2005. Another way to look at Maine's success in biotechnology growth is that the institutions in Maine positioned themselves well to take advantage of this enormous growth in public support for biomedical research.

The question that stands out is whether this rate of growth in public support can continue? The answer is almost certainly "no." Neither federal or state budgets are likely to be able to sustain these rates of growth given the competing pressures of other demands for funds and the general sense that taxes will not be raised And even if the answer is "yes," the competition for funds will be much greater in the future than in the past.

Maine has not been alone in seeking to ride the wave of biomedical research funding. Across the nation, states have invested billions of their own dollars, plus attracted billions more in support from other sources. The governor of Massachusetts has proposed a billion dollars in state funds for stem cell research, while the voters in California approved $3 billion for stem cell research. A private donor has offered North Carolina over $300 million to convert old textile mills into an entirely new campus of the University of North Carolina devoted to biotechnology research.

Maine's ambitious plans for new and expanded research institutes will have to be met in what will probably be a different funding environment than that which has sustained growth in biotechnology. At the very least, Maine is probably going to have to run faster in terms of funding just to stay even with other regions seeking to do the same things. Maine, like other states, will probably also have to adapt to changes in the biotechnology institutional and capital landscapes as Big Pharma and venture capital evolve to survive and to address the serious long term issue of a lack of profitability in the biotech firms portion of the biotech sector.

5.2 Clusters

Knowledge & Skills Foundations

Maine has two clearly distinct foundations of knowledge in biotechnology: genetics/genomics and antibodies/diagnostics-related knowledge. These are distinct areas of advantage for Maine. Solid research is undertaken in both areas, and both are capable of producing products for intermediate (non-therapeutic) markets. In commercial activity, products based on diagnostics-related knowledge are currently somewhat ahead in commercial applications.

But the knowledge/skills foundations of biotechnology are not limited to these two areas. Significant growth and expansion of the knowledge and skills in numerous additional areas is already underway and likely to increase further if current plans to expand education and research are met. As the analysis in Chapter 3 demonstrates, biology and biomedical science research is the real star of Maine's R&D's strengths. It is likely that the knowledge/skills foundations for biotechnology will include several additional areas within the next decade, but it cannot yet be predicted which areas those will be.

Cluster Status

Biotechnology in Maine currently has two areas which have elements of clusters: biomedical research and diagnostics. These are clusters with different characteristics and at different stages.

Potential Clusters	Genetics/Genomics Other Biomedical
Emerging Clusters	Diagnostics & Antibodies
Sustainable Clusters	

Biomedical research has many of the characteristics of a cluster including tight interrelationships among institutions, a degree of competitive success (at least from the point of view federal grant funding), a high degree of innovation and increasing evidence of sustainability over time. There is a strong concentration in genetics and genomics owing to The Jackson Laboratory, and a diverse array of other research areas which are emerging in several other research centers. Most biomedical research activity in Maine is currently not directly connected to commercial products, so we place this activity in the potential cluster category (for a discussion of the stages of cluster development see Chapter 2).

The diagnostics cluster is an emerging cluster. It has many of the classic characteristics of a cluster, including commercially successful firms, close inter-relationships, a solid knowledge foundation in the region, and good related and supporting institutions. Yet we still classify it as emerging mostly because it is still a small cluster, with many small organizations. The institutions, particularly the private sector firms, are dynamic, and have also sustained themselves over several decades since Ventrex started it all. The challenge in this emerging cluster is to gain sufficient size and scale that it can become a driving force in the Maine economy.

One of the exciting things about biotechnology is that it has the capability of producing many potential clusters over the next decade. These clusters will probably evolve from new applications of genetic knowledge into a variety of applications. One of the key elements in the forthcoming evolution of biotech clusters will be the extent to which Maine adds ability to directly serve human health therapeutic markets to what will be an expanding service to intermediate markets. This will probably come about, at least in part, through expanded connections with the rest of New England's biotechnology sector in ways that are not yet currently clear.

Cluster Characteristics

- Innovation

There is no question that the biotechnology sector in Maine is highly innovative in terms of research and new knowledge generated. Translating the new knowledge into commercial innovation has not occurred at the same rate as the growth in research activities and outputs. This mismatch between commercial innovation and research innovation stems from many sources, including the type of research undertaken in Maine and the still-young character of many research organizations in the biomedical fields.

- Regional Business Functions

Maine remains, from an employment point of view, still heavily oriented towards the beginning end of the R&D pipeline in biotechnology simply because of the size of the research enterprise in comparison with the commercial enterprise. One of the big questions about how biotech in Maine will evolve is whether the growth in biotech firms will occur through simply growth in new firms each having a specific role in a larger network or whether biotech firms will vertically integrate forward. Forward vertical integration would mean that more product development, manufacturing, and marketing would be carried out by the biotech firm. Furthermore, if a biotech firm forward integrates, would that additional activity also take place in Maine? These are unanswerable questions at this point.

- Entrepreneurship

A high degree of entrepreneurship is needed to sustain biotechnology, and the evidence to date indicates that Maine does not suffer for lack of entrepreneurship. New biotech firms have been formed from old firms, from research institutions, and from the universities in exactly the pattern typical of biotechnology over the past three decades. As always with Maine, however, there is the question of size. There are good examples of many different types of entrepreneurs in biotechnology, but each type may only have one example. As with so much of biotechnology, the question is not the presence or absence of an essential ingredient, but the amount available.

- Financing

The financing of biotechnology research consists of two distinct flows. The basic research is primarily funded by government sources, principally the National Institutes of Health. The other source of financing is private financing. This comes in two major forms: investment, particularly in young companies, designed to grow the company. Venture capital is frequently mentioned for this purpose, but venture capital is only form of investment capital that may be secured. As with other industries, public capital investment is also important. Biotechnology is also unique in that a great deal of financing for commercial development comes in the form of alliances between larger and smaller biotech firms to do specific product development work. As noted, these alliances are emerging as a more important source of financing for biotech in general.

As noted in Chapter 3, Maine, particularly The Jackson Laboratory, is a high volume recipient of NIH funding. Other research organizations such as MMCRI, are gaining increasing success in securing NIH funds, but whether past success is a predictor of future success is open to question. Maine has clearly demonstrated some success in attracting private capital to biotechnology development; although the Maine Technology Institute data indicate that grants remain the highest proportion of MTI biotech clients' funding among the seven sectors.

There is evidence of some venture capital investment and of some emerging alliances with larger biotech companies, but the shift towards more market-based funding of biotech is going to have to be a product of a growth in commercially-viable product development. But given the very particular expectations of venture capital investors, it might be expected that a major share of funding for biotech development research may have to come from alliances between biotech and pharmaceutical companies, which is becoming a standard approach within the overall industry. But

Maine will have to move more directly towards developing therapeutic rather than intermediate products for this to happen.

- Relationships

One cannot help but be impressed by the relationships that have been built within Maine biotechnology over the past few years. The Biotechnology Association of Maine, after a somewhat moribund period, has been invigorated with new leadership and is almost universally cited as a key resource for the sector. The Biomedical Research Coalition has also been highly effective at bringing organizations with different missions and backgrounds together. New collaborations reflected in such organizations the Graduate School of Biomedical Sciences and the Maine Institute for Human Genetics and Health (MIHGH) are based on equally solid foundations. In a sector where networking and relationships are the key to success wherever the activity is located, Maine has not lagged in any significant respect in this regard.

- Location Advantage

Why should biotechnology activities be located in Maine? The Jackson Laboratory provides one answer–to be at one of the world's centers for research into mammalian genetics. Another answer is provided by the website of the Maine Institute for Human Genetics and Health, which invites its readers, assumed to be potential members of the Institute to:

- **Imagine** working with world-class geneticists and other bio-scientists in an environment that encourages collaboration and entrepreneurship.
- **Imagine** living in Maine, a destination of unparalleled natural beauty that draws millions of visitors from around the world each year and inspires awe at every turning.
- **Imagine** excellent schools, safe communities, affordable housing, culture, and recreation all within a short drive of both the Atlantic coast and New England's best ski areas.

In this view, Maine's advantage lies both in the scientific opportunities and the fact that it is not Boston, at least from the point of view of the individual's life style. Interviews at other institutions suggest this view of Maine's location advantage is shared beyond MIHGH.

One measure of the ultimate success of biotechnology in Maine will probably be when organizations recruit new researchers using the first bullet point alone. The conditions of the second and third bullet points will hopefully still hold true, but Maine will be known as a top place to do science regardless of other attributes and amenities. Maine is not there yet, and may take some time to get there. The necessary preconditions will be, above all, achieving some level of scale beyond The Jackson Laboratory and creating highly effective networks within Maine that are also embedded in larger New England networks.

5.3 Economic Trends

Recent History

Maine has experienced strong job growth in its biotechnology sector, broadly defined, in recent years, boosting its employment base by 17 percent during the 2001 to 2005 period. The industry employs 3,712 across 124 business establishments. Its biotech location quotient, at 0.91 in 2005, nearly meets the U.S. average employment concentration (see Table 18).

> For information on the selection of the reference states used in the analysis, see Appendix 1.
>
> For more detail on the employment data and analysis, see Appendix 2.

The biotechnology sector in Maine is diverse, with roughly equal shares of employment in three major industry groups: life sciences R&D, medical equipment/supplies, and drugs/pharmaceuticals. These three industry sectors have each fared well in recent years by adding to jobs and contributing to overall job growth in the biotech sector. Both life sciences R&D and drugs/pharmaceuticals increased their employment by 12 percent. Medical equipment companies increased their payrolls by 38 percent from 2001 to 2005 with all of the jobs coming from 2004-05. However, the medical equipment industry is dominated by firms in industries such as prosthetics, dentures, and related products that primarily reflect the overall growth in healthcare services in Maine. Medical equipment primarily serves the local Maine market, which makes Maine's lead in biotechnology in Figure 21 somewhat misleading.

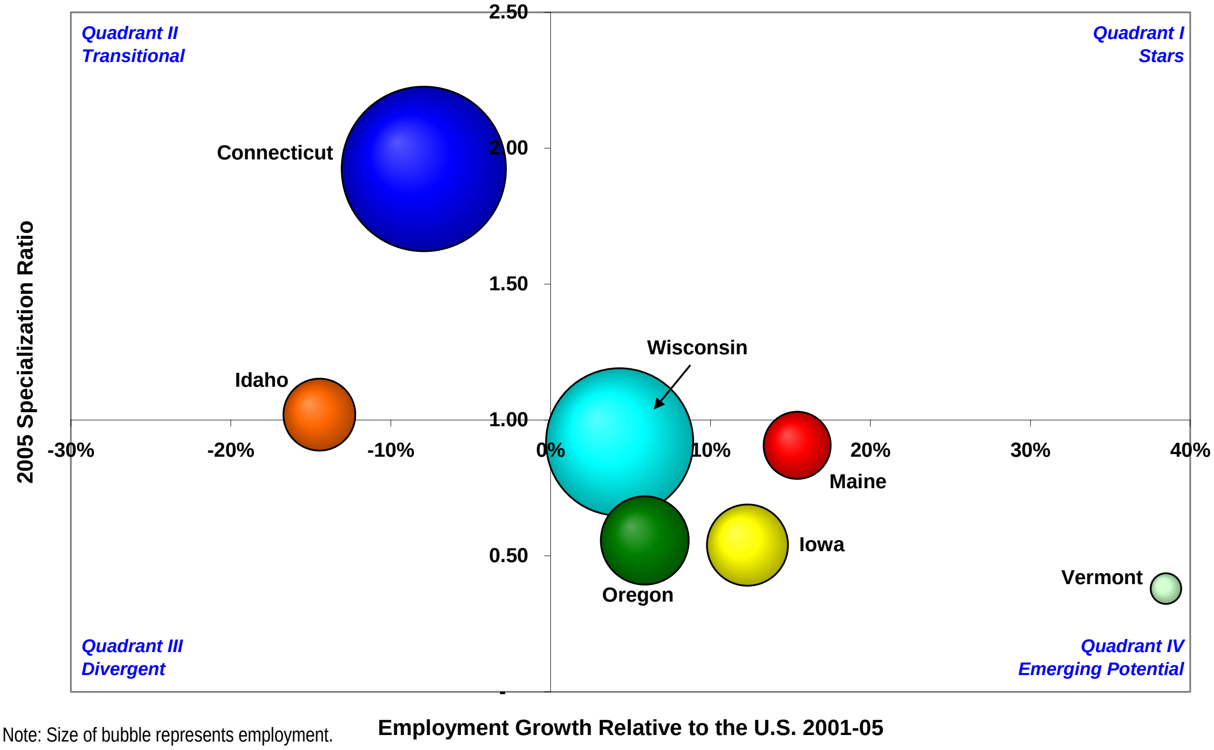
Compared with the benchmark states selected for this analysis, Maine has seen more rapid job growth than all except for Vermont, which has a smaller overall industry. Connecticut has the largest and most highly-concentrated biotechnology sector, though its employers have cut some jobs since 2001.

MAINE	*Total Private Sector*	*Biotech*
Establishments		
2001	43,232	105
2005	45,189	124
2001-05 % change	4.5%	18.5%
Employment		
2001	496,432	3,162
2005	495,554	3,712
2001-05 % change	-0.2%	**17.4%**
Average Annual Wages		
2001	$ 28,397	$ 40,020
2005	$ 32,106	$ 46,727
2001-05 % change	13.1%	16.8%
Specialization Ratio		
2001	1.00	0.78
2005	1.00	0.91
UNITED STATES		
Establishments		
2001	7,733,520	24,670
2005	8,308,128	25,552
2001-05 % change	7.4%	3.6%
Employment		
2001	109,321,800	895,792
2005	110,634,500	913,427
2001-05 % change	**1.2%**	**2.0%**
Average Annual Wages		
2001	$ 36,159	$ 61,237
2005	$ 40,499	$ 73,980
2001-05 % change	12.0%	20.8%

Source: Battelle analysis of BLS QCEW data from IMPLAN.
Note: Figures in Red denote specialized industry location quotients. Figures in Blue denote positive employment growth during the 2001 to 2005 period.

Table 18 Economic Performance: Biotechnology

Figure 21 Biotechnology Employment Trends



Note: Size of bubble represents employment.

Though it remains slightly below the U.S. average in terms of relative job concentration, the Maine biotechnology sector can be considered an emerging one given strong job growth in recent years. Especially encouraging is the diverse nature of the sector in Maine and the job growth occurring in each of these subsectors and industries during the mid-2000s.

- Market Potential

The market potential for biotech has been seen as virtually limitless (Oliver 1999). In some senses this is not unreasonable. One can scarcely conceive of limits to the markets for products to improve human health (not to mention animal and plant health). But the more recent research by Pisano suggests that exuberance for the market potential of biotech should not become irrational, since there remain daunting problems of science and management, not to mention profitability, to overcome (Pisano 2006).

The most lucrative end of the biotech product pipeline, the creation of new therapeutic drugs for human use, is also by far the most costly part. It is also undergoing profound changes as the nature and role of pharmaceutical companies is under challenge here and abroad. Most of the profits for the major drug companies, who ultimately market most of the products of biotechnology, come from a few major "blockbuster drugs," and the high costs of developing those drugs are recouped primarily in the largely unregulated prices paid only in the United States. Whatever the merits of the current system of drug development and use, it is a system fraught with instabilities that do not augur well for continuation into an indefinite future.

First, biomedical research is a significant and growing enterprise which already plays an important role in the Maine economy. It is primarily an export industry in the sense that most of its "sales" are to customers (the National Institutes of Health, etc.) outside of Maine. At the same time, the biomedical research activities are the foundation upon which future commercialization in the form of biotech firms will rest. That they have not done so to date reflects in part, the nature of the institutions, such as The Jackson Laboratory's primary mission in basic science, or their still young status, as in the case of MMCRI.

The potential for growth in the existing clusters and the creation of new clusters of biotechnology activity in Maine is strong. But just as Maine is finally climbing on board what has been a very fast moving train, we are likely to find that our past efforts will be insufficient for the future.

5.4 Summary

Maine has developed distinct knowledge and skills bases in genetics/genomics and the development of commercially-successful products in the diagnostics markets based on knowledge of antibodies and related biochemistry/biology fields. The large and growing volume of research indicates potential clusters which may emerge in the future, while the diagnostics/antibodies industry represents a current emerging cluster. However, biotechnology clusters are very small scale in Maine.

The keys to growing and strengthening these clusters include: continuing to support expansion of research and development in the biomedical sciences; expanding the workforce, particularly those with graduate training; supporting creation of new biotech firms; and linking to networks and alliances with major biotech firms for financing and product development.

6. Composites and Advanced Materials

6.1 Analysis

Composites and advanced materials present a clear case where the defining characteristics lay in a distinct set of knowledge and skills rather than any particular product definitions. The foundations lie in knowing how to combine different materials to make a product that is superior in some way from a similar product made from more traditional components or by traditional methods. The most obvious example is boats made from fiberglass instead of wood. Fiberglass boats are typical of what are called "fiber reinforced polymers" (FRP) which combine a fiber such as glass, wood, or carbon with a resin to create a material that may be lighter, stronger, more durable, or all of these. Fiber reinforced polymers have myriad applications in fields such as boat building and other transportation equipment, construction materials, and increasingly in products related to security and defense.

The most recent assessment of Maine R&D programs completed in 2007 contains a detailed assessment of recent trends in the composites and advanced materials sector (Policy One Research Inc and RTI International 2007). This study found many positive recent developments, including:

- Significant growth and diversification of research at the University of Maine Advanced Engineered Wood Composites Center, including high levels of patent and spin-off activities
- The development of well-functioning trade associations, including the Maine Composites Alliance, Maine Built Boats, and the Maine Marine Trades Association
- Steady growth in funding and economic activity
- Diversification of markets into construction materials and security equipment
- Significant levels of industry-sponsored research activities
- The U.S. Department of Labor WIRED grant to bring together industry, university, and workforce training/education resources to develop an integrated approach to composites-related development.
- The creation of the North Star Alliance Technology Fund to supplement MTI's support of the composites sector
- A well-functioning Advanced Technology Development Center in Sanford
- Plans for a composites training center in Brunswick, which will eventually be located on the redeveloped Naval Air Station Brunswick property.

Of the seven technology sectors, composites and advanced materials has, perhaps, the simplest definition of the core knowledge and skills. As Jake Ward of the University of Maine put it, "we have learned how to stick stuff together." That knowledge comes out of a number of disciplines including chemistry, physics, chemical and mechanical engineering. The University of Maine has become a leading center for research in these areas as they apply to the development composites and advanced materials through the Advanced Engineering Wood Composites Center and also the Laboratory for Surface Science Technologies. The research strengths of composites is also clearly shown in the research assessment in Chapter 4. Of the 18 "research clusters," composites ranks 11th in strength, while among the "research clusters" directly related to Maine's technology sectors, it ranks 7th. If the related field of research in advanced coatings, depositions, membranes & films is added to wood, FRP, and composites, this field ranks third among all research in Maine overall and among the technology sector research.

The research-innovation-commercialization process is, at base, working with the properties of combining materials to try to make an improved product. The central element of this business model is a close relationship between the shop floor, the testing lab, and customer relations. Maine's current strength in this arena revolves around the interplay among:

- Several successful boatbuilding and construction material businesses;
- Research centers at the University of Maine; and
- The Advanced Composites Training Center (ACTC) in Brunswick.

The nature of information exchange involves:

- Experimenting on the shop floor with different combinations of materials; this occurs routinely within companies, but also between companies as employees shift their employment and as composite-using companies and composite-supplying companies in Maine interact with one another;
- Field testing the new ideas at the AEWC; and
- Training workers in the newest production techniques at the ACTC.

An advantage cited in Maine is the willingness of vendors supplying materials to the composite producers to vary their own practices to enhance the tinkering process of innovation. One example is provided by Correct Deck which involved a vendor supplying a coloring additive. The vendor's primary market was for plastic products such as disposable ice cream spoons where the texture of the product was smooth and shiny. Correct Deck asked the vendor to experiment with various textures and to incorporate stain resistance characteristics. After considerable experimentation, both texture and stain resistance qualities were achieved. The result is a superior product, greatly enhancing Correct Deck's brand in the market.

Correct Deck's experiences illustrate an emerging set of "backward" or supplier linkages within Maine. Kenway is perhaps the most diversified composites business in Maine serving markets from boats to aquaculture to paper mills, and is an example of an increasingly forward-linked company. Having a wide variety of products enables the company to offset the ups and downs in any single market by moving its skills to whatever market proves strongest at any particular time. In addition, by installing its products, it has developed a reputation as an efficient and productive service provider. Plant managers, seeing how well and how quickly its engineers and technicians complete an installation at one plant, invite it to another. Its reputation for skilled work serves as its best marketing technique.

Kenway's diversification not only among its product lines but also into the installation and service end of the business is another illustration of the increasing role that services play in the successful marketing of products. This characteristic of increasing the service component of the production process was noted in the biotech section above, and will be seen in the discussion of other technology sectors below. An important factor crucial to the success of manufacturers moving to provide more value added services is a flexible workforce committed to improving productivity and innovation. Several interviews stressed the need to find engineers who can easily shift between the shop floor, the testing lab, and the customer's facilities to develop new adaptations.

Success of this sort depends on a regular and open flow of information among vendors, testing labs training centers, and often even among potential competitors of exactly the type characterized as knowledge spillovers in Chapter 2. This, in turn, requires confidence among the participants that the information exchanged is accurate and that it will be used to expand markets for all participants. In fact, several businesses noted that they frequently encounter ideas for composite products that they do not have the capacity to explore, but pass on to colleagues at the testing and training centers. If they, in turn, could pass such ideas on to businesses with skills or interests in such products, Maine as a whole would gain.

In short, we find that many of the key attributes of a cluster are present in the field of composites and advanced materials in Maine. A key question is whether as a cluster it shows evidence of being sustainable. On the one hand, the evidence of sustainability is fairly strong. After all, 2007 is the 400th anniversary of boat building in Maine, and if today's boats are a far cry from the *Virginia*, built at the mouth of the Kennebec in 1607, it is because of the type of technological innovation that has been essential to keeping this sector thriving. "Maine Built Boats" is now a brand that is increasingly recognized as distinctive and highly valued, as evidenced by the influx of potential buyers from around the world who attend the Maine Boat Builders show each year in Portland.

Other evidence of sustainability comes from more recent history. As discussed below in the section on Marine Technology and Aquaculture, Bath Iron Works assumed a very large R&D role in the late 1990's because of changes in defense procurement policies in the Clinton Administration. These policies were reversed by the Bush Administration with the result that BIW lost essentially all of its R&D functions. An important portion of that research was to have been in the application of composite materials to the construction of naval vessels. However, the shift in naval procurement has opened up new opportunities. Hodgdon Yachts is seeking, in cooperation with the AEWC, to build a composite-hulled high-speed motor craft to support naval special operations. The prototype of this new craft was recently launched and began sea trials and an intensive evaluation period.

Success in the composites advanced materials sector is now bringing challenges. AEWC has become such a key resource that it must now develop more explicit strategies for its future. There are difficult questions about whether the Center should do more applied field testing or more research and discovery. There are also questions about whether the ACTC should focus exclusively on composites or broaden its service to a more general type of advanced manufacturing. Industry representatives interviewed also debated whether MTI should fund more precise commercialization investigations or more cluster enhancement activities. These questions arose frequently among industry participants and present a challenge to all of the composites and composites-related trade associations and to their relationships with university and community college officials.

There are also some serious questions being raised about the adequacy of the workforce, at both the research end and the production end. On the research end, the Policy One-RTI evaluation found the production of Ph.D. engineers in critical specialties lagging, with no real growth over 2001-2005 in masters- or bachelors-level degrees. At the production end, the North Star Alliance's WIRED program is attempting to ensure an adequate workforce, while the community colleges, particularly through SMCCs Advanced Technology Center in Brunswick, have made efforts to increase relevant educational programs.

The North Star Alliance, which secured the $15 million in federal funding for this workforce development initiative, is unique among the technology sectors in that it represents the type of network among trade associations, firms, university researchers, and educational institutions which is typical of clusters. The Alliance is a good example of a formal network, and a key to its long-term impact will be the ability of the members of the Alliance to sustain their network when the federal funding expires and relationships must be carried forward using more informal networking connections.

6.2 Clusters

Knowledge & Skills Foundation

This sector has perhaps the most-clearly defined set of foundation skills and knowledge. That foundation is the knowledge of how to combine materials of different types to produce new materials that are lighter, stronger, more resilient and durable plus the skills to convert these materials into a variety of useful products. This knowledge/skills base is well established in the research and education institutions and in the commercial sector. It is being further enhanced by the WIRED program, a U.S. Department of Labor funded program to enhance the skills and trained workforce in composites applications and products.

Cluster definitions

Potential Clusters	
Emerging Clusters	
Sustainable Clusters	Developing new materials by combination of dissimilar materials or finding new applications for existing materials

Of the seven technology sectors, composites and advanced materials is the one "new technology" sector that comes the closest to equating the sector as a whole with sustainable cluster. There are strong cluster characteristics, as set out below, plus a track record of continuous innovation that should continue into the future.

Innovation

Innovation, as one business owner said, is very rarely a "great leap forward." Rather, it is a continual process of incremental changes. In a sense, being in the composites business is about constant innovation, i.e., tinkering. The innovations in this sector have flowed steadily from both the research institutions and the private-sector firms, both in partnership with one another and separately. This sector presents a very good example of the kind of innovation processes flowing from a body of knowledge accumulated within a region that should typify a cluster.

Regional Business Functions

While composites and boatbuilding are linked in a general way, in fact, only a selection of boat builders are deeply involved in using the more advanced forms of composites. There is great potential to strengthen the cluster and spread the knowledge of composites further in the boat-building industry by supporting the composites training center in Brunswick and the boat-building-apprentice and systems-integration programs in Rockland. Mid-Coast Maine has the potential to become a truly world class center for composites applied in the boat-building industry.

Entrepreneurship

The essence of the composites industry is finding new ways to make existing products; thus it has attracted the entrepreneurially oriented from existing industries—in boatbuilding, in plastics, in construction. In other words, this is a sector and a cluster in which spin-offs are very important.

Financing

Due to of the large number of spin-offs, the composites industry is composed mostly of companies that have built themselves into the composites field from other products and have thus brought their financing with them. Some spin-offs, such as those from AEWC, face the classic challenges of financing for the entrepreneurial start-up. For the industry to reach the next level of growth, it needs to attract new start-ups and, therefore, to encourage more external financing. Data from the MTI evaluation indicate that this sector was particularly successful in attracting venture capital, though this may be more the exception than the rule. Research grant support will remain important, but the strong commercial success of composite products should make it easier for financing sources to acquire a greater understanding of the nature of the industry and of the support mechanisms that exist in Maine that make investments in Maine composites and advanced materials less risky here than elsewhere.

Relationships

Overall the sector has developed strong institutions in all parts of the research-commercialization cycle. Through their evolution from non-composites-based businesses, the industry has brought with it a solid set of relationships with vendors and the AWEC. These relationships have been strengthened significantly through the work of the participants in the WIRED-grant funded by the U.S. Department of Labor.

Location Advantage

Maine has a natural geographic advantage in boat building and the use of wood as a raw material. The majority of the resins it uses are produced in the Midwest. However, whatever location advantage Maine has in composites arises from the knowledge and skills that have become embedded in the research and private sector institutions within the state. It is this advantage that will be the foundation of expansion of this sector beyond the "home base" of wood and boats.

6.3 Economic Trends

Maine has a highly-specialized composites and advanced materials sector, with a relative employment concentration that is about 70 percent greater than the national average (The specialization ratio is 1.73). The state industry employs 1,297 and spans 90 business establishments. While Maine lost 149 jobs, or almost 11 percent since 2001, this is similar to the national sector which experienced a 7 percent job loss since 2001 (Figure 22).

For information on the selection of the reference states used in the analysis, see Appendix 1.

For more detail on the employment data and analysis, see Appendix 2.

The composites and advanced materials sector in this context is made up of two somewhat different sub-industries—boat building and the resin, synthetic rubber, and artificial fibers/filaments industry. Maine's employment base and specialization in this advanced materials cluster is derived from its strength in the boat-building sector. In the industry definition, "boats" are defined as watercraft not built in shipyards and typically designed for personal use. Maine has added seven boat-building establishments since 2001, but has had relatively flat (and on net, negative) employment.

The Maine composites and advanced materials sector might be considered "transitional" in the bubble chart terminology. It is highly specialized, but is falling off somewhat in its growth. Nationally, this industry group has had similar declines, though it regained some footing by an increase of jobs from 2004 to 2005. Oregon went against the negative growth trend, as its boat building sector grew by 67 percent.

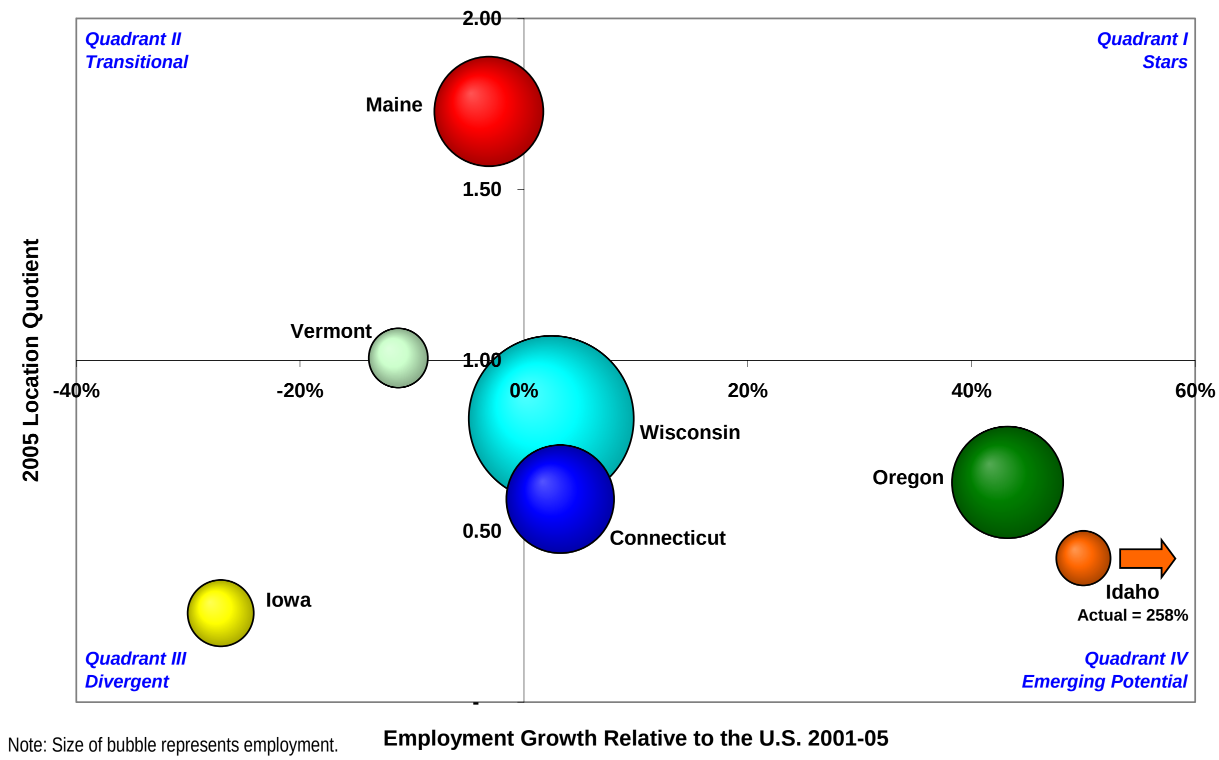
Economic Performance

MAINE	Total Private Sector	Composites & Advanced Materials
Establishments		
2001	43,232	81
2005	45,189	90
2001-05 % change	4.5%	10.6%
Employment		
2001	496,432	1,447
2005	495,554	1,297
2001-05 % change	-0.2%	-10.3%
Average Annual Wages		
2001	$ 28,397	$ 28,744
2005	$ 32,106	$ 36,247
2001-05 % change	13.1%	26.1%
Specialization Ratio		
2001	1.00	**1.76**
2005	1.00	**1.73**
UNITED STATES		
Establishments		
2001	7,733,520	2,850
2005	8,308,128	2,799
2001-05 % change	7.4%	-1.8%
Employment		
2001	109,321,800	180,636
2005	110,634,500	167,651
2001-05 % change	**1.2%**	-7.2%
Average Annual Wages		
2001	$ 36,159	$ 49,021
2005	$ 40,499	$ 54,547
2001-05 % change	12.0%	11.3%

Source: Battelle analysis of BLS QCEW data from IMPLAN.
Note: Figures in Red denote specialized industry location quotients. Figures in Blue denote positive employment growth during the 2001 to 2005 period.

Table 19 Economic Performance: Composites and Advanced Materials

Figure 22 Composites and Advance Materials Employment Trends



Market Potential

Maine has a solid presence in one composites-related market, emerging presences in two others, and the potential for many others. The boat building sector has shown real competitive strength over the past two decades, which has been particularly important given the decline in the demand for fishing vessels. Lobster-boat building remains an important part of the Maine boat-building industry and companies such as Kenway have found some niche markets for composite boats. The Hodgdon Yachts venture into naval vessels holds the promise of another potential market. However, the real strength in boat building has been in the construction of high-end yachts for the recreational boating industry. These yachts, which are much larger and more complex than the recreational boats of a generation ago, are the perfect application for the lighter and stronger materials made possible by composite technologies. World demand for such yachts remains strong and Maine has found a solid competitive position in both national and world markets which it should be able to maintain so long as demand remains strong.

Emerging markets are in the construction materials and security-related products areas. Composites have a number of advantages in construction applications, and companies such as Kenway, Harbor Technologies, and Correct Decks have formed to take advantage of these opportunities. The AEWC has also been working with the Army to apply composites technologies to the protection of forces in Iraq and Afghanistan, where there is critical need for lightweight materials that will resist bullets and improvised explosive devices (IEDs). IEDs are seen as a major security threat not only in foreign theaters of war, but increasingly at home (Hsu 2007). The market for security-related composite materials is thus likely to see substantial growth.

Beyond these markets, there exist numerous applications of composite technology that are just barely beginning or are still not clear. In Chapter 7, the possibility of composites being used in the construction of wind-energy equipment is mentioned as a possible element in an emerging cluster of alternative-energy technologies. Composites may also play roles in such technologies as in-stream tidal power, and in the development of "green products" using recycled materials.

6.4 Summary

Composites & advanced materials is the technology sector which as a whole best approximates a sustainable cluster in the sense developed in this study. The sector and its industries are grounded in a clearly defined set of knowledge and skills which are strongly identified with Maine. Both formal and informal networks have arisen to develop and widely diffuse the key knowledge and skills. There is strong evidence of entrepreneurship in the historic boat-building industry, which has adapted to new market conditions, and in new companies looking to find new markets for products made from composite materials. Finally, there is a substantial critical mass of commercially-successful firms that are selling in global markets products based on the knowledge and skills centered in Maine.

7. Environmental Technologies

7.1 Analysis

The Environmental Technologies sector is unlike any of the other six considered part of Maine's "technology economy." It is not organized around a single technological area, such as information technology, nor is it organized around a key input such as forest resources or output such as aquaculture, nor even around any particular production process like precision manufacturing. It is, rather, defined primarily by the markets that are served, and indeed by a particular characteristic of those markets–the need to avoid or remediate damage to the environment, defined to include everything from the local environment of a particular site to the global environment.

This sector has made substantial progress in forming an organizational identity for itself since the 2001 study, when it was categorized as "seeking direction." A small but very active trade association, the Environmental and Energy Technology Council (E2 Tech) has been formed and now has over 130 members from the public, private, and non-profit sectors. The Council defines the sector as having three major sub-sectors:

> **Environmental Services** is the largest category (by employment) and consists primarily of environmental engineering, waste disposal/recycling, testing laboratories, and hazardous waste management.
>
> **Environmental Equipment Providers** are primarily manufacturers of equipment and machinery for waste collection/treatment, monitoring, and pollution control for both air and water.
>
> **Environmental Resource Management** firms include water utilities and waste recycling facilities, as well as the large and growing field of renewable energy resource production. In this latter category are organizations involved in bio-fuels, wind/hydroelectric power, as well as technologies such as solar and hydrogen.

Using these definitions, a study commissioned by the E2 Tech Council and undertaken by Todd Gabe at the University of Maine found that there were over 680 firms in these sub-sectors, with a total employment of more than 5,200 jobs and $223 million in wages (Gabe and Noblet 2006). The Environmental Services sub-sector is the largest accounting for about two thirds of the firms in the sector. Environmental-resource management accounts for most of the balance of the sector, with environmental products only a relatively small proportion of the sector.[12]

One of the most important findings of the Gabe study is that Maine ranks 14th among the states in the proportion of their businesses which can be described as part of the energy-environmental technology sector. This supports the impression that many people have that Maine is a place where concern for the environment is a catalyst to economic activity.

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[12] This may be an understatement of the size of environmental products as firms in many manufacturing industries may be destined for environmental protection/remediation a\markets but cannot be readily identified as such.

The diversity of this sector as a whole presents real challenges in identifying clusters, but there are elements that have definite cluster characteristics. One is clearly the field of environmental services, including that part of this sub-sector that is grounded in civil engineering. This field has sufficient size and other characteristics to denote it is a sustainable cluster.

Environmental engineering is reported by Gabe to be the largest component of the sector, and interviews with firms in the field show a vibrant industry operating both within Maine and elsewhere. Woodard and Curran, the largest of the environmental engineering firms in Maine, and also a Maine-based company, is in the top 100 environmental engineering firms in the country according to *Engineering News Record.* International firms, such as Stantec, are now also operating in Maine.

Analysis of occupational distributions in Chapter 4 shows that Maine has a strong specialization in its workforce for environmental engineers, though it is somewhat less specialized in civil engineers. Maine has also seen growth in 2000-2005 in environmental engineers at more than twice the national rate, and also grew about the same rate as the nation in civil engineers. Similar patterns are seen in the occupational category environmental-science/protection technicians.

Environmental engineering appears to be well supported by the College of Engineering and its programs in civil and environmental engineering at the University Maine. Firms indicate that the College provides a steady stream of high-quality graduates. Civil engineering specifically, and all branches of engineering more broadly, comprise the core skills and knowledge around which this cluster will be organized.

Environmental engineering and related services have another characteristic that is potentially important in shaping the cluster: the strong influence of what Porter calls "local demand conditions." In this view, the competitive advantage gained from location in a particular region is strengthened when that region is a place with "tough customers." Proximity to tough customers gives firms an opportunity to establish and maintain a high degree of interaction with those customers and to continuously expand their knowledge about what those customers need and want. This process is critical to the firm's long-term competitive success in other markets because if the firm can keep the "tough customers" in their own backyard happy, they are likely to be successful with customers anywhere.

A good example of this dynamic at work is Clynk, a Maine-based company in the bottle-recycling business. Maine has one of the most comprehensive recycling laws for beverage containers, which leads to some frustration by customers and recycling facilities who must separate many different types of containers in order to recycle them. Maine people have become very familiar with the recycling machines at most grocery stores where plastic bottles and aluminum cans are separately collected.

Clynk addresses the issues of customer convenience by conducting the sorting process through a sophisticated application of machinery and software that permits the customer to just drop a bag of mixed returnable containers off at a location and receives a refund in the form of an electronic store credit. The system has been in place at a select group of Hannaford Brothers stores, and will soon be in all Hannaford stores in Maine. Plans exist to extend the system to much larger states with bottle bills, such as Massachusetts and New York.

The comprehensive Maine bottle bill provided the challenge to meet a need for increased customer convenience, to which a technological innovation offered a response. In the case of Clynk, additional support came from MTI, which funded research into the software needed to make the system work, from the U.S.M. School of Business which assisted with some of business planning aspects, and from a variety of other resources in Maine. Most interestingly in the case of Clynk is that the venture capital needed to transform an inventor's idea for an automated bottle-sorting system into a commercial enterprise also came from within Maine.

W.H. Shurtleff offers another example of this process. A Maine-based family company founded in 1890 as a food wholesaler, Shurtleff later became a distributor of industrial chemicals and salt. As opportunities in these industries declined, the firm shifted under its fourth-generation owner to providing the equipment and services to manage storm-water runoff during construction projects. The company sells both products and services to municipalities and construction companies in this field. Demand for storm-water management grew dramatically over the past decade as federal and state water pollution efforts focused more and more on issues of nonpoint pollution.

In sum, the environmental services area has several key attributes of a cluster including an established competitive position in Maine and beyond, a solid base of knowledge and skills that is provided within Maine, and local demand conditions that spur competitive advantage.

In contrast, the environmental products industry is much more difficult to characterize in cluster terms, but this should be neither surprising nor distressing. The sheer size and diversity of products destined for environmental protection/remediation markets is growing and there remain many opportunities for growth in this area in Maine, growth which may coalesce around specific products, as suggested by the situation in the environmental-resources sub-sector.

One aspect of environmental products that is already clearly showing some impact is the area of "green" or "sustainable" certification for products. Maine already has a "Green Lodging" program for hotels and similar establishments. Other major areas where this approach is being taken include "Green Buildings" and "Sustainable Forestry." National and international organizations have developed standards that must be met to be certified as environmentally appropriate. Maine is already the home of many "green" buildings and over a million acres of Maine forest land has been certified as sustainable. Seven Island Land Company is a leader in this field.

The development of "certified green" programs greatly expands the definition of environmental products, for it extends the concept to many everyday products that would not be captured in a traditional industry-based analysis. It also opens up major new potential markets for many Maine companies, and offers a potentially-important new path for innovation for those companies wishing to "go green."

As defined by the Energy and Environment Technology Council, the Environmental Resource Management sub-sector includes water and waste-water utilities as well as solid waste management and recycling facilities. These sectors serve local markets within Maine although some solid waste is imported for burning in the waste incineration facilities. These industries within the sub-sector are a mixture of publicly-owned and operated and privately-owned and operated facilities and do not have the same types of competitive pressures or technology-innovation pressures found in other sectors and sub-sectors. The combination of these industries with the environmental services sub-sector does create a number of opportunities for firms in the environmental products industries to expand their range of products and product applications.

The other major component of the Environmental Resource Management sub-sector is renewable energy. Here, Maine has long had an important role in technological development and use, primarily in the state's extensive hydroelectric system, development of which began more than a century ago. As fossil fuels and nuclear power became the dominant sources of electricity, hydroelectricity receded, except for periodic proposals for major development at some of the last major hydro sites such as the Dickey-Lincoln project on the St. John River and the Big Ambejackmockamus ("Big A") falls on the Penobscot.

However, concerns over nuclear safety and global climate change have dramatically altered the energy picture. It is clear that energy from renewable sources with low carbon "footprints" is currently in great demand, and this demand is expected to grow significantly in the coming years. New technologies such as in-stream tidal power[13] may come to play an important role in the future, as Maine is one of the few states on the east coast with natural conditions suitable for such technology. But the two major renewable energy sources of interest are likely to be bio-fuels and, especially, wind energy.

Bio-fuels include ethanol, which is added to gasoline in order to provide an ingredient with similar combustion characteristics to gasoline, but with lower emissions. In the U.S., ethanol is increasingly used in many areas with high air-pollution problems, including Maine. It is currently derived chiefly because of large Federal subsidies for its production from this grain, and is, thus, not produced to any significant degree in Maine. Although some corn grown in Maine may be sold into the ethanol production markets, due to the very high demand for the raw material, this is unlikely to grow to any significant scale.

However, corn-based ethanol is seen as having a number of potential drawbacks, including driving up the price of food and requiring almost as much or even more energy to produce as it provides when used. Cellulosic ethanol is seen as very plausible alternative to corn-based ethanol in terms of performance and emissions, but with a much lower cost in terms of the energy (and carbon emissions) needed to produce it. There are many potential sources of cellulosic ethanol, and one of the most important is wood chips (Economist).

Wood chips are, of course, already a source of energy in Maine both for home and limited commercial heating, and as the primary fuel for a number of wood-to-electricity, or biomass, fueled facilities which have been built in Maine since the 1980's. The number of such plants in Maine has declined as natural gas has assumed a larger role in providing New England's electricity. Conversion of wood chips into ethanol could provide a major new industry for Maine's forests if the biochemical processes needed to efficiently convert wood cellulose to energy can be addressed.

Research to address these issues is currently underway in Maine and elsewhere. Small-scale pilot plants are under construction elsewhere in the U.S. and cellulosic ethanol will need government support of the type currently being lavished on corn-based ethanol. Since corn-based ethanol is currently using most of the government funding, primarily it can be produced with existing technologies, the future of wood-based ethanol is still uncertain, and most likely not to materialize for another five to ten years as a major commercial enterprise, if it ever does. However, bio-fuels from wood may dramatically change the forest products industry in Maine in coming years. More discussion of this aspect is found in the section on the forest products industry.

Biodiesel is another possible development area for Maine. Biodiesel is a fuel that has many of the same characteristics of petroleum based diesel fuel, but it is made from biological products such as used cooking oils. The Chewonki Foundation in Wiscasset has been a leader in Maine in developing small-scale biodiesel production and in using biodiesel in its fleet of vehicles. A number of fuel companies, such as Frontier Energy in China (Maine) is already supplying biodiesel mixed fuel to a number of large-fleet customers in Maine, and a storage facility for biodiesel has been built in

[13] In-stream tidal power utilizes high-efficiency turbines placed in the tidal flow and generate electricity with the necessity of building barrages (or dams) of the type that have been proposed in the past for the Bay of Fundy and Cobscook Bay. They are essentially wind turbines in the water.

South Portland. Maine has also reduced the tax on biodiesel from 27.9 cents on standard diesel to 20 cents on biodiesel, and a biodiesel users group is being formed.

These operations are still small scale, and so it is not yet clear whether biodiesel can become the foundation for a competitive cluster in Maine. If it were to become a cluster it would likely be through the development of technological and commercial inter-relationships among feed stock suppliers (such as restaurants), producers, and distributors. Maine already appears to have a foundation of research, engineering, and commercialization from which a cluster might emerge, but the scale of current activities would have to significantly increase to transform this potential cluster into an emerging cluster.

Biodiesel is already the best established bio-fuel in Maine; and it has grown fairly significantly over the past few years. Biodiesel is used almost exclusively in fleet vehicles with diesel engines and this is likely to remain the case since diesel cars cannot currently be sold in Maine because of concerns about NOx and particulate emissions. However, auto makers, particularly in Europe, have developed new cleaner diesels that may reopen the automobile diesel market in the U.S. This would be a potentially much larger market than it has been in the past because of high fuel prices, which are likely to persist. Whether these cleaner diesel engines would effectively use biodiesel is still an open question, but it seems likely that adaptation for biodiesel would be forthcoming at some point.

The other major element of renewable energy growth in Maine is wind energy. Wind energy is already well established in the state with two different scales of operation: utility-scale and private-use scale.

Private-use scale wind power plants dot the landscape throughout Maine and are increasingly found in a variety of locations from commercial to residential. Communities such as Scarborough are looking to develop zoning ordinances to manage the siting of wind generation equipment in residential neighborhoods, and there are a number of firms which install and service wind equipment for private users.

Utility-scale wind facilities are much larger facilities, using much larger turbines, to produce electricity for sale to the wholesale power grid. It is the utility-scale facilities which have attracted by far the most attention. Wind energy is perhaps the fastest growing source of electricity in the world. Some countries such as Germany, Denmark, and the United Kingdom are already getting substantial portions of their electricity from wind. Wind energy facilities are also rapidly growing in the United States.

Like hydroelectricity, wind energy is inherently tied to regions which have certain natural features of topography and climate to make wind a reasonable source of energy. In New England those features are found generally in the mountains and at the coast. The first utility-scale wind facility in Maine is already running at Mars Hill in Aroostook County. Proposals are under review by the Land Use Regulation Commission for facilities in the western Mountains, and still more proposals are in the early development stage. The largest by far would be the Linekin Bay proposal which would be located in the St. John Valley of Aroostook County and would, at 500-600MW of capacity, rival the natural gas or oil-fired generating facilities that provide most of Maine's electricity.

Issues around the development of wind energy in Maine are complex. On the one hand, the State has clearly committed itself to an increase in renewable electricity sources as part of its energy policy in a bill enacted in 2006. By 2017, renewable energy must account for 10% of electricity supplies in Maine. At the same time, Maine has joined ten other states in the Northeast in the Regional Greenhouse Gas Initiative (RGGI), an effort to reduce the emissions of greenhouse gases in the northeastern U.S. Moreover, many of the states in the RGGI have enacted requirements for electricity production from renewable sources that are even higher than Maine's. These commitments will sustain a lively market for non fossil fuel energy generation in New England, despite the removal of similar mandates for renewable energy production in the Federal energy bill passed in December 2007.

These commitments to lower greenhouse gases and to renewable energy clearly imply a greatly expanded use of wind energy for no other technology currently commercially available will meet both objectives. At the same time, wind energy is controversial because it requires large, highly visible equipment to be placed in what are often locations with high scenic or other natural values. Opposition to virtually all wind power projects has arisen wherever they have been proposed. The Governor has created a commission to examine the issues surrounding wind power siting, and other states are struggling with similar issues.

Another major issue that has been critical to wind energy's development has been Federal tax policy. A tax credit for the construction of wind energy facilities has been offered sporadically over the past thirty years. The credit has been renewed and allowed to expire through several cycles, and each cycle has been profoundly influential in the amount of investment that has been made in wind energy facilities and in the technology of wind energy. Current federal law makes the credit permanent which should further encourage the growth in wind energy.

A significant expansion in wind energy in Maine is thus likely over the next decade unless market conditions or state or Federal policy dramatically changes. The question for the current context is whether this growth will have economic development implications beyond those that will arise from the construction of the wind facilities. There has already been some effect; as one person in the industry indicated, a "small army" of consultants have developed expertise in wind energy siting as a result of proposals for wind facilities in Maine. Wind energy is thus already contributing to the diversification of the environmental services sub-sector, and this contribution seems likely to grow.

There is some expectation that the growth in wind facilities in Maine could stimulate the development of manufacturing of turbines and related equipment in Maine. However, the manufacturing of wind turbines, blades, etc. is already well established in many countries. Turbine equipment for Maine projects is sourced from Europe or elsewhere in the U.S. as virtually all parts of wind turbines can be transported anywhere in the world. Currently there is no particular reason why wind energy equipment needs to be manufactured near the site of installation.

There is, however, a possibility for Maine to seize a share of the world wind energy equipment market. The amount of energy generated by a given turbine is a function of the size of the turbine and blades. As the size of the turbine increases, power output goes up, and power output goes up faster than the size increase. But as size goes up, so does weight and weight is a major factor in installation, particularly in remote mountain environments where very large cranes must be used to lift the turbine to the top of the tower. An important direction for technological development in wind energy is therefore to develop means of building bigger but lighter turbines, towers, and blades.

Here may lie opportunities for Maine's composites and advanced materials cluster. The major technical advantages of various composite technologies are in the ability to make products that are light and stronger and, when necessary, bigger. The problems faced by wind energy equipment manufacturers are similar to those in boat building or aircraft manufacturing and for which the composites industry has been working to provide solutions. A combination of capital investment and technological development could establish an important new market for the composites cluster which could greatly increase its competitiveness and sustainability.

7.2 Clusters

Knowledge & Skills Foundations

Potential Clusters	
Emerging Clusters	
Sustainable Clusters	Environmental services and engineering, civil engineering related to the environment

The environmental and energy sector covers such a diverse array of activities that it is difficult to define a clear knowledge/skills foundation. Perhaps the clearest is to be found in those areas of civil and environmental engineering and environmental services which assist private and public sector organizations to minimize or remediate environmental impacts. There are clear strengths in these fields in Maine both at the University of Maine and in the relatively robust private sector of environmental services. The focus on this sector should not obscure the diverse array of other scientific and technical knowledge about the environment that exists in many places within Maine.

Energy related knowledge and skills has largely been confined in Maine to the generation and transmission of electrical energy, for Maine has historically been a supplier of electricity based on its natural resources (including rivers and wood). There are major shifts underway in the technological basis for "clean" energy, including the development of wind powered electricity generation, in-stream power (tidal power which does not require barrages), and bio-fuels made from plant residues. Each of these areas is seeing different patterns of concentration of knowledge and skills. Wind power technology has been largely developed in Europe, where it was deployed at significant scale many years before the growth in the U.S. That expertise is spreading to the U.S. and Maine's knowledge and skills base in composites and advanced materials may give Maine an entrée into this technological field. The technologies of in-stream tidal and of bio-fuels (other than corn-based ethanol) are still in the early stages of development and regional centers of knowledge have yet to become established. Elements of renewable energy may evolve into a cluster in Maine, but this will be in the future.

Cluster Characteristics

- Innovation

In terms of product development, the MTI evaluation shows that the environmental sector grant recipients tended to be the lowest among the seven sectors in terms of developing new products and getting new products to market (at least at the time of the annual reporting). On the other hand, MTI grant recipients in this sector were among the highest in reporting they expected to get the product within two years. Environmental products innovators among MTI recipients also scored relatively high in patent activity. Given the relatively scattered and small size of the environmental products subsector, this may not be surprising.

Innovations in services related to the environment are much more difficult to measure, but are nevertheless critical. One area where there is clearly a great deal of innovation occurring is in the number of firms in diverse industries that are looking to take part in the "green certification" movement for various products and services. Innovation also appears in new ways of addressing older environmental problems such as recycling bottles, as evidenced by a company such as Clynk.

- Regional Business Functions

A large and diverse array of businesses in this sector exists in Maine, with the environmental services industry having both strong inter-relationships within Maine and serving markets in and outside of Maine. The diversity of environmental products manufacturing makes it difficult to provide an overall characterization of that sector. It is noteworthy that MTI grant recipients in this sector indicate they will source the highest proportion of their materials inputs from within Maine of the seven sectors, indicating some strength in the environmental products sub-sector that is not apparent from other data. Strong regional business functions in renewable energy have not yet developed.

- Entrepreneurship

Entrepreneurship appears to be strong in this sector. According to the University of Maine study, over half of the firms in the environmental technology sector have two or fewer employees, indicating a larger number of start up and young companies. This very high proportion may also indicate barriers to entry may be low, but barriers to growth may exist. These barriers certainly include the traditional barriers to growth for young companies: finding financing, learning how to manage larger organizations, market development, etc.

- Financing

The point made above about barriers to growth for smaller companies is perhaps reinforced by the MTI evaluation data, which also show that the Environmental sector is the smallest receiver of external debt and equity financing. MTI grant recipients are somewhat more highly dependent on grants for revenue.

- Relationships

The sector is well served by trade associations with accompanying opportunities for interaction. It is also well served by the University of Maine System, particularly the College of Engineering at the University of Maine.

- Location Advantage

There is a distinct location advantage for this sector's operations in Maine. Part of this is clearly geographic as Maine is well situated for growth in renewable energy such as wind and tidal power. But much of the advantage stems from Maine's long established commitment to environmental protection and remediation which makes Maine a very good location to operate a locally and nationally or internationally competitive business. At the same time, firms in this sector are concerned about the costs of doing business in Maine, ranging from taxes to health care to transportation links.

7.3 Economic Trends

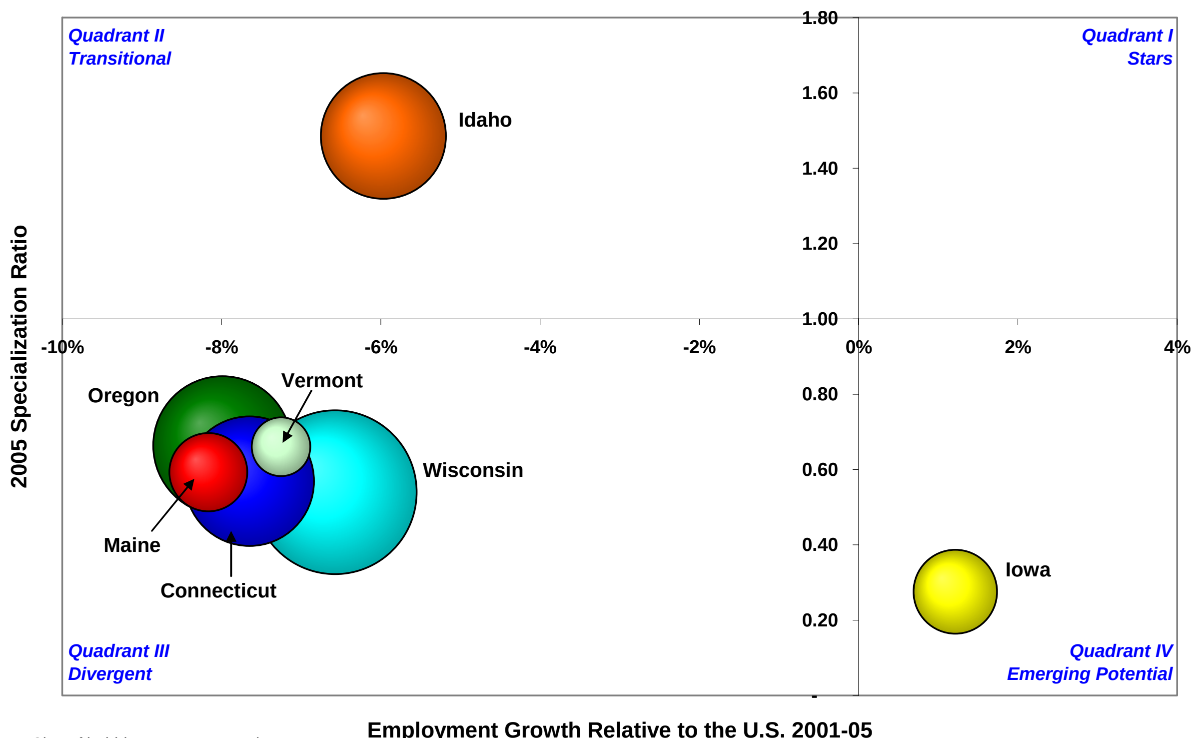
Engineering & Other Scientific/Technical Services

For information on the selection of the reference states used in the analysis, see Appendix 1.

For more detail on the employment data and analysis, see Appendix 2.

Engineering and other scientific and technical service providers in Maine operated 622 individual business establishments and employed 3,196 workers in 2005. Not all of these establishments served environmental markets; the largest non-environmental markets served are in construction. Since 2001, job growth in this Maine cluster was essentially flat (up 0.7 percent). At the national level, however, this technical services sector experienced rapid growth, rising 8.9 percent since 2001. The national growth arrived in 2004 and 2005 after declines during the sluggish labor market years following the recession of the early 2000's. So despite a slightly positive growth rate for Maine, state growth relative to the U.S. is substantially weak (see **Error! Reference source not found.**).

Figure 23 Economic Trends: Engineering and Technical Services



Note: Size of bubble represents employment.

The vast majority of Maine's environmental services subsector is made up of jobs in the engineering services industry. This industry includes a wide array of activities including the applications of engineering principles to design and development of machines, materials, instruments, structures, systems, and more. Technical services in this field require a high level of skill and training; and thus, industry employers tend to offer higher wages to attract talented professionals.

In the bubble chart, Iowa shows strong job growth in this consulting/services sector but has a very low concentration of jobs relative to the U.S. (Specialization Ratio is 0.28). Similar to Maine, the majority of Iowa's engineering and other scientific services sector is in engineering services. Idaho has a specialized cluster, with a specialization ratio of 1.49 but has shown slow growth relative to the U.S.—2.9 percent since 2001 versus 8.9 percent, respectively.

MAINE	Total Private Sector	Engineering & Other Sci/Technical Services
Establishments		
2001	43,232	541
2005	45,189	622
2001-05 % change	4.5%	14.9%
Employment		
2001	496,432	3,173
2005	495,554	3,196
2001-05 % change	-0.2%	**0.7%**
Average Annual Wages		
2001	$ 28,397	$ 50,525
2005	$ 32,106	$ 55,834
2001-05 % change	13.1%	10.5%
Specialization Ratio		
2001	1.00	0.63
2005	1.00	0.59
UNITED STATES		
Establishments		
2001	7,733,520	77,650
2005	8,308,128	93,175
2001-05 % change	7.4%	20.0%
Employment		
2001	109,321,800	1,104,633
2005	110,634,500	1,202,891
2001-05 % change	**1.2%**	**8.9%**
Average Annual Wages		
2001	$ 36,159	$ 62,148
2005	$ 40,499	$ 72,302
2001-05 % change	12.0%	16.3%

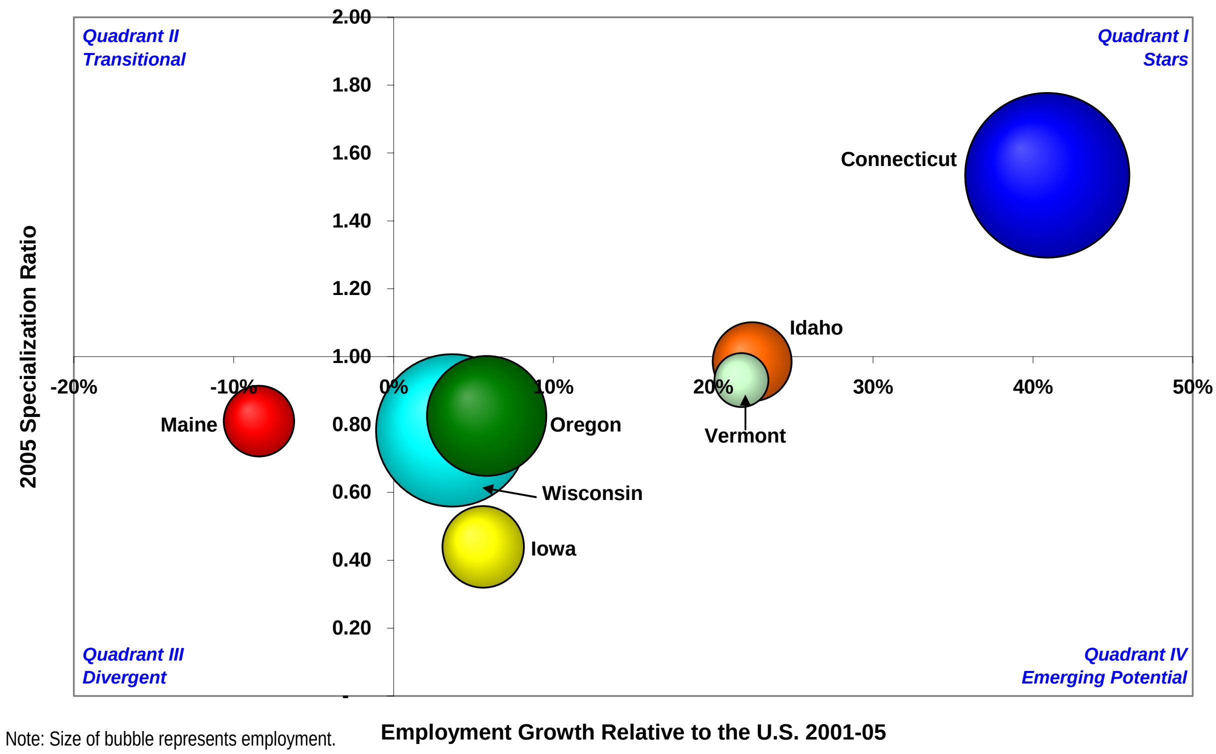
Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 20 Economic Performance: Engineering and Technical Services

Environmental Services & Alternative Energy Generation

Maine's environmental services and alternative energy generation firms operated 264 business establishments employing 1,743 people in 2005. After shedding jobs in 2002 through 2004, the sector had a slight employment increase in 2005. On net, sector employment is down 7.1 percent during the 2001 to 2005 period. Its location quotient in Maine stands at 0.81 for 2005. Nationally, the sector is up 1.3 percent since 2001 (see Figure 24).

Figure 24 Economic Trends: Environmental Services and Alternate Energy



Looking at the subsectors, Maine has a fairly even distribution in terms of jobs. Remediation and other waste management services leads the sector with just over 500 state jobs. Testing labs, waste treatment and disposal, and environmental consulting services follow with roughly 300 jobs each. It is important to note that analysis in this report and with respect to this industry cluster includes only private sector firms and employment. Public waste collection, water treatment, and utilities employment are not included in this analysis.

Compared with its selected benchmark states, Maine has fared poorly in terms of job growth/loss in recent years. While Maine lost jobs in the sector, each of the other benchmark states had net job growth. Connecticut stands out with a large, specialized, and growing environmental services and alternative energy cluster. While Connecticut's remediation and waste management sector is large and established, it has seen impressive growth in its "other electric power generation sector" from just 54 jobs in 2001 to more than 2,500 in 2005. This industry reflects the alternative power generation aspect of the cluster and includes electricity generated from renewable sources.

MAINE	Total Private Sector	Environmental Services & Alt. Energy
Establishments		
2001	43,232	252
2005	45,189	264
2001-05 % change	4.5%	4.8%
Employment		
2001	496,432	1,877
2005	495,554	1,743
2001-05 % change	-0.2%	-7.1%
Average Annual Wages		
2001	$ 28,397	$ 38,078
2005	$ 32,106	$ 42,511
2001-05 % change	13.1%	11.6%
Specialization Ratio		
2001	1.00	0.87
2005	1.00	0.81
UNITED STATES		
Establishments		
2001	7,733,520	35,273
2005	8,308,128	37,262
2001-05 % change	7.4%	5.6%
Employment		
2001	109,321,800	474,414
2005	110,634,500	480,458
2001-05 % change	**1.2%**	**1.3%**
Average Annual Wages		
2001	$ 36,159	$ 47,682
2005	$ 40,499	$ 53,613
2001-05 % change	12.0%	12.4%

Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 21 Economic Performance: Environmental Services & Alternate Energy

- Market Potential-

The market potential in Maine, nationally, and globally for the products and services of the environmental technology sector must be considered strong to very strong. Concern about the impacts of human activity on the environment is now widespread and the market for products and services to address or avoid those impacts is already strong and likely to get much stronger in the decade ahead. The most identifiable candidate for very strong growth is clearly in renewable energy simply because of the increasing recognition of the imperative need to address climate change. But there are other markets that are also likely to show significant growth such as "green certified" products.

7.4 Summary

This is a highly diverse sector from which has emerged a clear set of directions in the fields of environmental services and engineering. Maine has a definable advantage in the knowledge and skills in this area, with a diversifying set of activities to meet growing markets. Maine's own commitment to a high quality environment serves as a spur to innovation in this field which may permit national and global markets to be served. The environmental services subsector is the one part of this diverse sector that has the characteristics of a sustainable cluster.

Other parts of the sector are not of sufficient size or organization to characterize them as clusters. The environmental products subsector is difficult to measure, but it still somewhat small. Renewable energy has had up and down cycles in Maine, and is very likely poised for a significant up cycle over the next decade. There is growth potential in both these subsectors which may very well yield clusters in Maine within the next decade. The worldwide demand for certified "green" products is already growing rapidly, as is the role that Maine will play in renewable energy production using technologies such as wind.

8. Forest Products and Agriculture

8.1 Analysis

Forest products and agriculture present a very different picture in many ways than other technology sectors. Little about these sectors is what is thought of as "high tech." Both are quintessentially Maine industries in the sense that they have comprised the economic foundations of the state since before Maine was a state. These very characteristics help bring sharper focus to the real nature of clusters and innovation. Sustainable clusters of innovative activity can be found in both sub sectors, each relying on the same combination of research designed to improve productivity and to develop new products to serve increasingly smaller niche markets. Each has an array of historic networks supporting it, and each has a well established skilled workforce in Maine. Each also has a large number of commercially-successful firms struggling to find a way in globally competitive mature markets.

Forest Products

Maine is the most heavily forested state in the nation. Over 80% of its land mass is covered in forest, and this proportion has been going up in recent decades. The same cannot be said of the industries that depend on the forest resource. The past decade has seen unprecedented competitive pressures on these industries. For the first time in more than a century there has been a significant decline in paper making capacity in Maine and the closure of a number of key mills. The lumber and secondary wood products industries have reduced capacity as a result of competitive pressures. A biomass energy industry has endured a wild boom and bust cycle in less than two decades.

Five major subsectors comprise the forest products economy:

- Forestry and forest harvesting. This sub sector comprises the firms engaged in management of forest resources and in the harvesting of wood.

- Pulp and paper. The largest subsector by value of production, it includes integrated mills which produce both pulp, paper or both.

- Lumber and structural products produces products for three uses: dimensional and related lumber for construction, specialty products such as oriented strand board, and wood used as input by other forest products industries, including the inputs to specialty wood-products producers and byproducts such as chips which have been used in both pulp and energy manufacturing.

- Other wood products divides into two categories: furniture and wooden specialty items ranging from croquet sets to architectural products such as door knobs.

- Energy. Waste wood has been used as an energy source in lumber and paper mills for many years, but a separate industry grew up in the 1980's to use wood as a fuel for generating electricity to be sold to the power grid.

Although each serves somewhat different markets and has its own unique issues, all of these subsectors are highly interconnected within the Maine forest products sector. Together, each of these sectors comprises an element in a system designed to extract maximum economic value from the vast acreage of woodlands in Maine. Forest managers must decide on long-term strategy for encouraging the growth of wood, but also must balance the needs of the wood using industries with other values including wildlife habitat, water quality, and recreation demand. The harvesting subsector must assure an adequate wood supply for the mills, but also manage the woods operations to comply with the multiple demands on the forest. The mills, whether saw, pulp, or paper, balance the supply of inputs with the changing demand for their outputs in Maine and elsewhere. Multiple markets for wood, whether as chips for an electricity producer, logs for structural lumber, or pulp wood, assure that the entire wood supply can be optimally used. It is fair to describe the entire products system as a sustainable cluster, with several smaller clusters operating within the larger cluster.

Forest products illustrate the principle characteristics of a "sustainable" cluster. The complex, integrated system of forest lands, users, and uses has permitted Maine to adapt to a number of significant changes in the forest economy over the past forty years. The story of Maine's adaptation to the 1970's outbreak of the spruce budworm illustrates this point. The spruce budworm is an insect which does substantial damage to the spruce and fir trees that are the bedrock of Maine's forest industries. It reappears in long cycles and can destroy tens of thousands of acres of trees in the space of a few years. The 1970's was the most recent appearance of the budworm and it put severe pressure on the timber supply that was then powering an expansion in Maine's forest products industry. The last completely new paper mill in Maine to be built, the Scott Paper (now SAPPI) mill at Skowhegan, opened at the height of the budworm outbreak.

The budworm catalyzed multiple responses. Woodlands management, including pesticide spraying, greatly intensified. Sawmills expanded to take advantage of the large supply of wood which suddenly had to be harvested in order to clear away large acreages of trees killed by the budworm. New and larger sawmills were built both in Maine and across the border in Quebec, which was actually closer to many of the budworm-damaged stands than any mill in Maine. The result was faster harvesting of the damaged trees and increased competition between Maine and Canadian lumber producers. The budworm also intensified the shift towards more hardwoods in Maine forest, which meant that pulp mills built to handle the unique characteristics of the spruce and fir fibers had to be re-engineered to take a much larger mix of hardwood. Scrambling to adapt to a changing forest resource, Maine pulp and paper mills also fell behind their international competitors who were investing in new mega-paper mills capable of nearly twice the output of most Maine mills, flooding the international market with pulp and paper and making it very difficult for Maine mills to quickly recoup their investments in new technologies.

The forest products industry of today is essentially the legacy of these events over the past twenty years. Trees grow slowly in Maine; fifty years is a standard rotation length for a typical stand of softwood, so the industry is barely halfway through the post budworm cycle. And all of the forces that built up during that period are still present, though there have been some important changes.

The most important change in the post budworm period has been the nearly complete restructuring of the forest products industry itself, which has manifested itself in two ways. The first is the dramatic shrinking of the industrial forest land owner. Beginning in the late nineteenth century Maine's forest lands were bought up by the growing paper industry. Companies founded in Maine such as Great Northern Paper and International Paper came to own millions of acres of woodland. In the early 1980's, Great Northern Paper was the largest land owner in Maine, with more than 10% of the state to feed its two mills in Millinocket and East Millinocket. A that time, every major mill (except for a few such as S.D. Warren in Westbrook) had its own timber lands to supply its mills.

As the globalization of the paper industry increased in the 1990's, paper companies decided that they no longer wished to be large land owners. Some companies, like International Paper, had effectively separated their land operations from their paper making operations by creating each as a separate profit center in the company. The result was the selling off of much of the land held by the major paper companies. About half was sold to other paper companies, such as J.D. Irving, which bought large tracts of land from International Paper and other companies for its paper mill in Saint John, New Brunswick. The other half was sold to a complex mix of owners which included real estate investment trusts like Plum Creek, whose sole business was the management of the land resource including insurance companies, "new timber barons," conservation and public agencies (like the Land for Maine's Future Program). As Figure 25 shows, more than 5 million acres (one quarter of Maine) has changed hands in a ten-year period (Hagan, Irland et al. 2005).

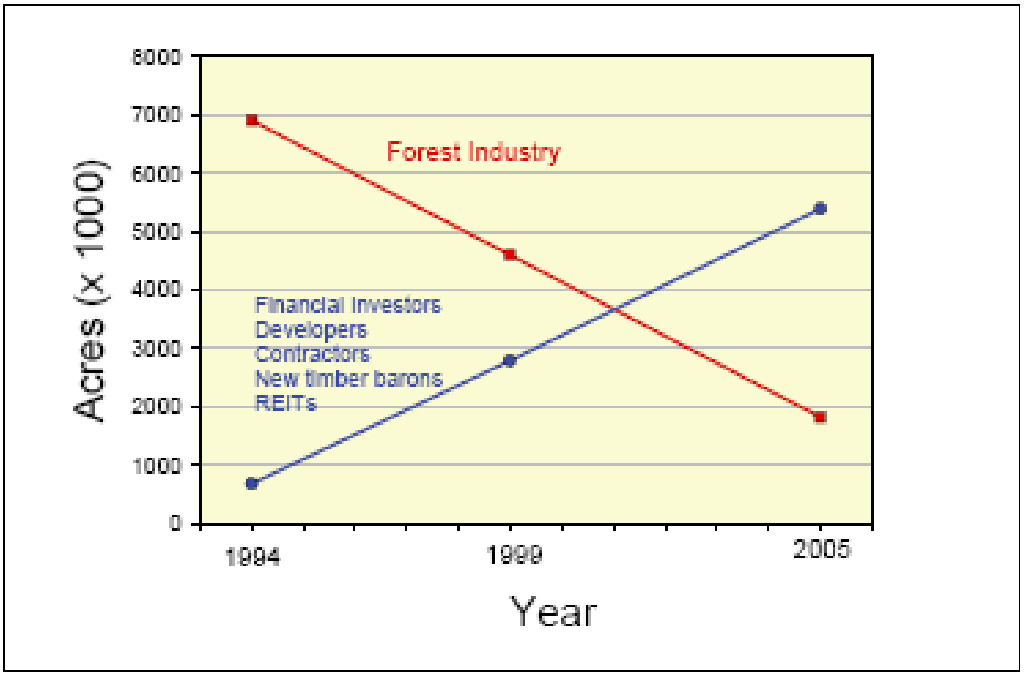


Figure 25 Changes in Maine Timberland Ownership 1994-2005
Source: Hagan et. al, 2005

The second major change is in the ownership of production capacity itself in the paper industry. Table 22 summarizes the major changes in ownership in the Maine paper industry since 1990. Three mills have closed entirely, and there has been substantial reduction in capacity at such companies as Katahdin Paper and SAPPI. Not shown in this table is the period in which Great Northern's mills were closed entirely, although they have reopened with a smaller number of machines operating. Only three mills, Fraser Paper, Madison Paper, have been largely unaffected by the changes in ownership/management. Lincoln Pulp & Paper's manufacturing facilities have remained intact, although the company's ownership changed after a bankruptcy and temporary closure.

	Ownership		
Town	1990	2004	2007
Woodland	Georgia Pacific	Domtar	Pulp only

Madawaska	Fraser Paper	Fraser Paper	Fraser Paper
Old Town	Georgia Pacific	Georgia Pacific	Pulp only
Jay	International Paper	International Paper	Verso
Bucksport	St. Regis	International Paper	Verso
Brewer	Eastern Fine Paper	Closed	
Millinocket	Great Northern Paper	Katahdin Paper	Katahdin Paper
East Millinocket	Great Northern Paper	Katahdin Paper	Katahdin Paper
Lincoln	Lincoln Pulp & Paper	Lincoln Paper & Tissue	Lincoln Paper & Tissue
Madison	Madison Paper	Madison Paper	Madison Paper
Rumford	Boise Cascade	Mead Westvaco	New Page
Skowhegan	S.D. Warren (Scott Paper)	SAPPI	SAPPI
Westbrook	S.D. Warren (Scott Paper)	SAPPI*	SAPPI
Jay	James River	Wausau-Mosinee	Wausau-Mosinee
* SAPPI has closed its pulp mill in Westbrook			

Table 22 Changes in Maine Paper Mill Ownership

Things have been no less turbulent in the rest of the forest products industry. Many of the independent energy-producer-owned biomass-fueled electric generation facilities have closed, though wood energy plants that are still operating in association with other forest products operations have showed considerable strength. The lumber industry has dropped from 115 establishments in 1997 to 102 in 2006. Among the specialty wood-products firms, there has been a rash of closing of specialty wood-producers making everything such products as dowels as China has essentially captured almost all the markets for these types of relatively standardized, but labor-intensive products. Imports of furniture from China have also soared, reducing the demand for Maine hardwood lumber mills' products, which went to supply domestic furniture-makers.

At the same time, Maine still does have strong firms in some product lines, such as pallet manufacturing and wood furniture parts and manufacturing, but the diversity of secondary wood products has declined. Moreover, Maine's wood products industry was able to take advantage of the booming housing construction market in the early part of this decade.

The net result of these changes has been a decline in the forest products industry in Maine from 1997-2005 as measured by the industry's contribution to Gross Domestic Product (GDP). Over that period, the combined GDP of wood products and pulp and paper declined from $2.004 billion to $1.691 billion (measured in 2000 dollars), a drop of 15.6%. The decline in pulp and paper, which measured 24.7% over this period, was the reason for the drop. Wood products, by contrast, increased their GDP by 31% over this period (compared with growth in the U.S. wood products GDP of 10.9%. These figures show both the real challenges to Maine's forest products industry, and its continued potential for success.

This complex mix of changing ideas about how to manage forest products companies in a global economy, changing ownerships, intense pressure from new competitors like China and old competitors like Canada has created a crisis in the forest products system in Maine that is comparable to the spruce budworm outbreak of thirty years ago. Looking back, the budworm fundamentally altered the forest products industry in Maine, but did not significantly damage it, at least in the near term. This time however, it is already apparent that Maine will not emerge unscathed from the current combination of forces at work. As the discussion in Section 8.3 shows, Maine has lost significant capacity, output, and employment in recent years.

Maine's forest products industry proved itself to be highly innovative in response to the budworm, and it will need to do so again in the face of current pressures. At the same time, however, because the pressures are reshaping in profound ways the very organizations that have to be innovative, it is much more difficult than in the period of the response to the budworm. Simply put, it is a time when being innovative is imperative, but it is a dreadful time to try to be innovative. This is one reason why a 2005 study of the forest products industry for the Governor's Council on Sustainability noted:

> the forestry and agriculture sector has applied for and received the fewest awards from the Maine Technology Institute, just 6% in the past three years. Also, many of the mill managers represented on the Advisory Council were unaware of either the Maine Technology Institute or the resources available at the University of Maine.

It is not that the capacity to be innovative is lacking. There are significant resources at the University of Maine in the School of Forest Resources, the Pulp & Paper Process Development Center, the Paper Surface Science Program, the Cooperative Forestry Research Unit, the Center for Research on Sustainable Forests, the Advanced Engineered Wood Composites Center (discussed in more detail in Chapter 6), and the Forest Bioproducts Research Institute. The Cooperative Forestry Research Unit (CFRU) is a model of higher education-industry cooperation in the conduct of basic and applied research. Forestry is identified as an R&D "mega-cluster" in Chapter 4, and there are significant elements of research in the crop and soil sciences, wildlife/habitat conservation, and wood/FRP/ composites that pertain to forest management. Natural resource and conservation degrees also showed significant growth over 1996-2006.

Beyond the University of Maine, there is a large stock of knowledge and skills in forest products held in the diversity of saw mills, forest harvesters, wood turning, and related firms throughout Maine. Robbins Lumber Company, a major producer of white pine lumber, is a good example of a company that has historic roots in Maine lumber, which has made investment in new technologies and process to compete including computer-controlled head rigs and edger optimizer which scan the logs to maximize lumber recovery; a co-generation plant that turns biomass into fuel; and facilities and equipment for painting lumber on-site before sending to market.

Workforce is generally not an issue in the forest products sector, as the large job losses in recent years have left a residual pool of available workers if needed. However, this is likely to be a short-term phenomenon in that workers will eventually move to other locations or to other careers. Moreover, the aging of the population in rural Maine and the out-migration of youth will eventually put a potentially severe constraint on available workforce. Young people are increasingly reluctant to commit to careers in manufacturing, even well-paying ones, since recent experience has suggested a high risk to being unemployed in these industries (Russell 2007).

Beyond the university/industry connections, the forest products sector has a dense array of networks in the form of trade associations, although organizations such as the Maine Forest Products Council, the Maine Wood Products Association, and the Maine Pulp and Paper Association are oriented towards government relations functions.

Although markets for most of Maine's forest products are very mature and slow growing, there are several developments in current and potential markets for Maine forest products that may open up a new set of opportunities for the industry. Probably the most important is the change in the international trade environment. Pressure by imported forest products, from clothes pins to printing paper, has been a major factor leading to the declines in Maine's industries. The sources of the international competitive pressure are complex, but exchange rates have been an important part of the story. In the 1980's when imports of Canadian lumber began to surge, leading to a nearly twenty-year trade dispute between the U.S. and Canada, the Canadian dollar traded at less than 70 cents U.S.

Today the Canadian and U.S. dollars trade at or near par. The dramatic fall of the U.S. dollar against most major currencies, including the Euro, has the effect of both reducing demands for imports and increasing the demand for U.S. products abroad. Forest products have historically been Maine's largest export products, and the current trade environment favors Maine producers in significant ways. Currency adjustments will not solve all of the industry's problems, but these changes will open doors that have been shut for many years. A weak dollar is expected to continue for some time.

Another change in the market is the rise in demand for "green" products. This is most significant for lumber, where the increased demand for lumber from "sustainable forest land" is being driven by the increase in green building standards. Seven Islands Land Company has been a pioneer in the use of third part sustainability certification procedures. It also shows up in the demand for recycled paper, which has been an important source of competitive advantage for Katahdin Paper. Both of these changes in the market create important innovation opportunities for forest management and for ways to make high-quality, low-cost pulp from the highly diverse fiber supply that is recycled paper.

The third change in forest products is the development of entirely new products from wood. Maine is already making substantial progress in this area on a number fronts. The leading edge of this innovation is clearly the development of wood composites, led by the AEWC at the University of Maine. In addition to developing new composite materials for the boat-building industry, AEWC is a leader in the development of Oriented Strand Lumber (OSL), a major part of the growing field of engineered wood products. OSL is used in place of traditional dimension lumber for structural applications; it has greater strength and high consistency. AEWC operates a pilot plant for testing of OSL and other engineered wood products. OSL is also becoming the major product of LP Houlton, a firm that once made oriented strand board (similar to plywood), and, after $110 million investment, is now set to be one of the largest producers of OSL in the U.S.

The next wave in the generation of entirely new products from wood is the conversion of wood into other products, including bio fuels (by turning cellulose into ethanol) and other products that can be used for pollutant remediation and products that resist degradation. The University of Maine has established a bio-products research institute with funding from the National Science Foundation. Research is underway at UM in bio-fuels development. Private investment has also been attracted to this technology, as a group of private investors have purchased the former Georgia Pacific paper mill in Old Town and plan to produce conventional wood products like pellets, engineered wood products, and bio-fuels. There is also research underway at the University of Maine to apply nanotechnology approaches to wood fibers which could open up additional ranges of new products from wood.

The technical and commercial success of engineered wood products and new bio-products from wood are still unproven. But they are clearly of interest well beyond Maine. New York State has put up $110 million for research in bio-fuels and to establish New York as the northeast center for bio-fuels research. If commercially-successful, bio-fuels and bio-products could create a major new demand for fiber from Maine forests.

Agriculture and Foods

Agriculture in Maine is only a small part of the nation's agriculture. In 2006, Maine produced 0.2% of the nation's farm output. Maine is also very different from the type of agriculture that dominates the landscape in the Midwest and Western U.S. Maine is a state of small farms. In 2002, the average farm in Maine was 190 acres compared with a U.S. average of 441 acres. Maine has a smaller proportion of its employment in agricultural production (1.3% v. a U.S. figure of 1.8%), but the same proportion in food-processing, marketing-related jobs (1.5%). Maine's principal products of potatoes, dairy, blueberries, eggs, and greenhouse/nursery products (2002) are primarily destined directly to consumer markets rather than being used for the production of intermediate products like animal feed or ethanol. The proportion of Maine's economy in agriculture, as measured by the proportion of total employment, is about the same in Maine (14.6% in 2002) as in the U.S. (14.3%) (U.S.D.A. Economic Research Service 2007).

The long-term trends in Maine agriculture are illustrated in Figure 26, which shows the number of farms in Maine in 1964 and 2002 for three major agricultural outputs: chickens, potatoes, and dairy.[14] The total number of farms producing just these three products fell by more than 10,000 in the 38 years between 1964 and 2002, or more than 82%. The fall in dairy farms accounted for nearly half (46%) of this drop. Chickens, particularly to serve the broiler market, were once a major Maine product, but railroad deregulation in 1979 made it uneconomical to transport corn from the Midwest to Maine to feed the broiler stocks. Broiler production fell from 69 million in 1978 to 20 million in 1982 and less than 50 thousand in 2002. Potato acreage planted has shrunk by over one half, mostly in Aroostook County. The number of dairy farms has dramatically dropped even as population and demand for milk has grown because of the complex dynamics of the New England dairy industry.

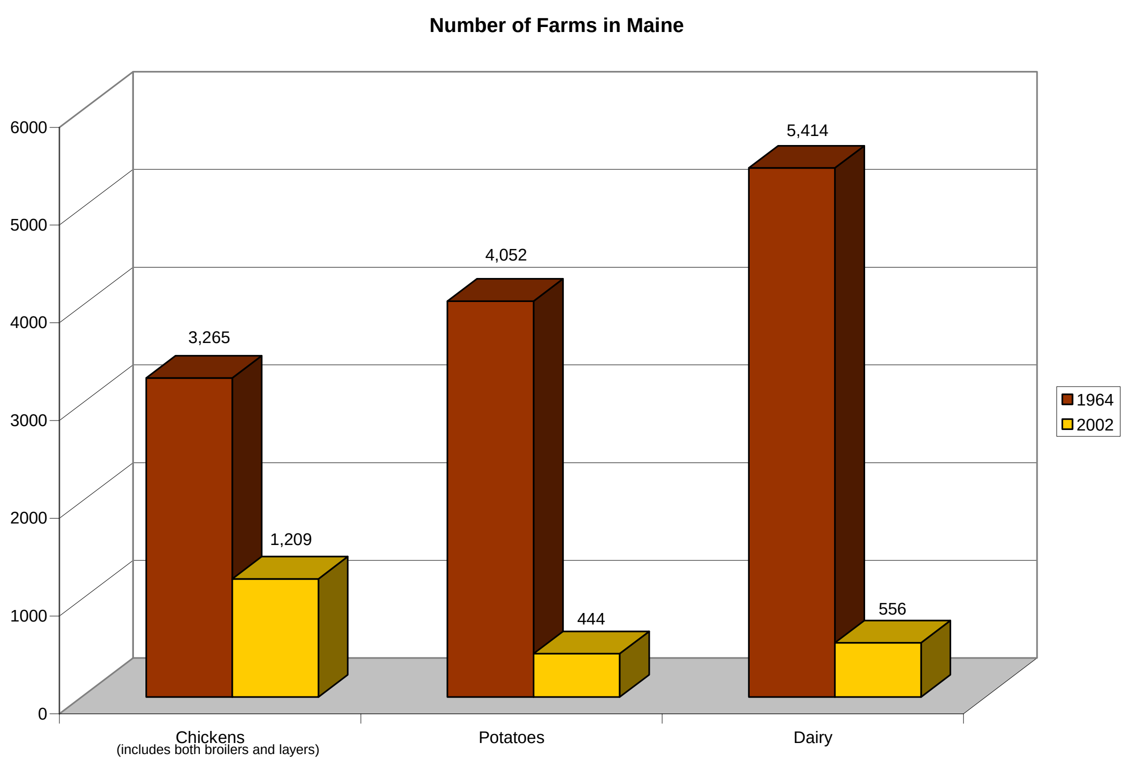


Figure 26 Number of Farms in Maine 1964 & 2002

[14] Source: Census of Agriculture, 1992 and 2002.

Not only does Maine have smaller farms than the U.S., the size of Maine farms has been shrinking faster than the U.S., down 13% in Maine between 1992 and 2002 compared with 10% in the U.S. More seriously, the number of farms with less than $10,000 in annual farm sales has risen in Maine from 56.3% in 1992 to 70.8% in 2002. At the same time, the number of farm organizations has actually *risen* in Maine. From 1992-2002 the number of farm organizations grew by over 1,200 or nearly 25% to 7,196. The vast majority of this growth was in individually- and family-owned farms. In sum, small-scale agriculture has grown significantly in Maine to go along with the larger-scale agriculture of potatoes, dairy, etc. The result, as detailed in Section 8.3 below, is that growth in Maine's agriculture and food sector compares favorably with national and reference-state trends.

These trends define clearly the twin innovation challenges facing Maine's current agriculture sector. On the one hand, there is a subsector of agriculture that is still in the commodity-production business. This is primarily in potatoes, blueberries, dairy, and, to some extent, in other crops such as apples. Firms in these businesses are concerned primarily with finding ways to increase productivity (measured, for example, by yield per acre), to lower the costs of production in order to improve income, and, where possible, to increase the value of their output by selling into higher-valued markets such as processed foods. Examples of the latter include French fries and providing blueberries as inputs to packaged foods. For many, if not most producers in these industries, the value-added strategies are designed for large-scale production.

At the same time, there is a large and growing movement towards smaller-scale operations with small outputs and very small, niche markets. In these, the key strategy is finding a way to process and add value to the raw inputs. Increasing production of cheese from dairy inputs is a good example, as are a large variety of other "specialty foods." The specialty foods market represents the major source of growth in the food and agriculture industries in Maine, though the operations are often very small. Because the operations are small, but the demands for quality high in these sectors, firms must find new ways to assure customers not only of a distinctive, but also of a safe, high-quality food product.

To these challenges to Maine's current agricultural sector must be added the prospects of technological innovation potentially creating a major demand that would return Maine farms to a high level of commodity production. As with the development of technology to transform wood into liquid fuels (discussed above in forest products), new technology is under development to create biodegradable polymers (plastics) from potatoes. This represents a third major innovation direction for agriculture.

The statistical picture of agriculture in Maine is dominated by the large commodity producers in things like potatoes, dairy, and blueberries. Despite the dramatic reductions in farms and farm output over the past forty years, agriculture remains, as a whole, commercially successful. Gross value added from agriculture was up in 2006 compared with 2005 by nearly $59 million, or 22%, resulting in a $54 million increase in net farm income, a 33% growth. All of the growth came in output from growing crops, primarily potatoes. The growth in farm income in Maine came at a time when national farm income was falling (U.S.D.A. Economic Research Service 2007).

The sources of this commercial success, which it should be noted can be highly variable from year to year depending on the weather and markets, has also changed in other ways. As noted, one of the most important changes has been the shift to production away from direct consumer use and towards processed and other products. This is most noticeable in the potato industry. In the early 1960's the majority of acres were devoted to the production of the Irish Round White potato, which was directly sold to consumers in what the potato industry refers to as the "table stock" market. In 2006, two thirds of potato acreage was devoted to growing for the processing market, with 18% going to seed potatoes and only 15% to the table stock market (Maine Potato Board 2007). The major French fry facility operated by New Brunswick-based McCain Foods plus the facilities of other companies such as Naturally Potatoes, most of which have been built or significantly expanded in the last twenty years, are the drivers of this shift to processing.

Another development in large-scale agricultural production is shaped by the increasing demand for locally-produced food, a trend which is also supporting the growth of small-scale specialty-food production as discussed below. Backyard Beauties is a company growing tomatoes in large greenhouses in Madison using technologies imported from Europe. To date, this is the only company growing vegetables at a large scale in Maine using this approach, but the technology could produce additional opportunities. USDA identifies greenhouse/nursery products as the fifth largest agricultural output in Maine, though this refers primarily to ornamental plants. Energy costs are a major issue for this industry in order to deal with Maine's long winters, but Backyard Beauties does suggest a new direction for Maine agriculture.

Maine's large-scale agriculture is backed by a significant research infrastructure, primarily at the University of Maine. The analysis in Chapter 3 identifies food/dairy sciences along with crop/soil sciences as two distinct areas of research advantage for Maine. The Battelle analysis of patents, grant funding, and publications finds that 14.5% of the records relate to these two fields of research. These strengths represent the University of Maine's role as the Land Grant University, and its historic role in agriculture and related research. The University of Maine is also the home of the Cooperative Extension Service, a unique organization involved in translating the work of the research community directly to users in the farm and business communities.

Maine's larger farm sectors are well served by an array of networking organizations from Cooperative Extension, which serves this role as well as translating research, to long-standing trade associations such as the Maine Potato Board, the Wild Blueberry Association of North America, and the Maine State Pomological Society. The Maine Department of Agriculture is also a very important network center with its multiple roles is assuring safe and productive farming techniques and to support market development for Maine products.

The agricultural workforce remains adequate in Maine, but as with much of U.S. agriculture, it has long depended on importing workers during harvest seasons. There is also the problem common throughout U.S. agriculture, and rural Maine, of an aging workforce, driven in party by the overall aging of the population and in part by the lack of young people entering agriculture. In this regard, the average age of farm operators in Maine in 2002 of 53.7 is actually younger than the U.S. average of 55.3. But the out-migration of youth from rural parts of Maine like Aroostook County exacerbates this issue of current and future workforce availability and costs.

These trends in larger-scale Maine agriculture appear in different ways in the emerging small-scale agricultural industries. The most important parallel is in the focus on higher value-added processed food. The examples among the specialty food products are too numerous to mention, but range from larger producers such as Stonewall Kitchen in York to Simply Divine Brownies in Freeport to Mothers Mountain Mustard in Falmouth and to Raye's Mustard in Eastport. There are over 6,000 jobs in food processing in more than 200 establishments in Maine.

Perhaps the most important characteristic of the small-scale specialty-food processors is that they are small businesses in a highly competitive environment with demanding requirements for technological sophistication to assure safety and quality. Many of these businesses start within the classical entrepreneurial fashion with an idea for a particular product. Often the ideas arise on farms, as farmers search for ways to diversify their income sources. Small-scale success from home-based production and, perhaps, sales at a local market or craft outlet leads to the opportunity to serve larger markets. This shift in opportunities very likely accounts for the growth in the very small farming organizations reported above.

Exposure to larger markets might arise from participation in a regional or national trade show or advertising in local and regional markets. The Maine Gourmet and Specialty Food Producers Association joined together for a State of Maine pavilion at the Fancy Food Show. This was the first pavilion sponsored in 18 years.

Success with one product may lead to others. Hancock Lobster is an example. They started with a frozen lobster stew product and have expanded to offering more than half a dozen products including lobster pot pie, seafood Newburgh, lobster Wellington, lobster rolls, lobster bake in a bag, crab dip, and lobster cakes. Hancock Lobster has done this with several Maine companies offering brownies, biscuits, and that traditional Maine food, Whoopie pies.

Success in small outlets may lead to larger outlets such as L.L. Bean or national food catalogs such as Harry & David or Williams-Sonoma to place orders for significantly-expanded amounts of production, which could be orders of magnitude more than what can be produced at home or in the small shops to which such firms often move as they shift towards full-scale commercial operations. What was once a hot product at the local market now faces the prospect of becoming a hot national product and with it all the problems of growth. These include finding financing, appropriate space, a workforce, and making the very difficult transition from shifting attention primarily on the product to the organization of the business. Production of safe and high quality products at much larger scale, and often at low unit prices demanded by the larger national outlets, completely transforms the business environment for the specialty food producer. The difficulty of successfully making the right decisions in each of these areas is the principal reason why so many small businesses fail to become large businesses.

The specialty food producer does have a number of assets in Maine which can assist in making these changes. The Brookings Report makes a case for the Maine brand (Brookings Institution Metropolitan Policy Program 2006), and it is clear from interviews of those in the specialty food business that being from Maine is a brand identifier that has significant value in the high-end market. The Maine brand works very well with a variety of specialty food products, but can be a challenge for other such as Cold River Vodka or Maine wineries which produce products rarely associated with Maine.

The technological challenges in the specialty-food-products area are actually quite significant. As productions and markets grow, the producer must find economical means to preserve freshness, package, store, improve shelf-life, and ship. All food processing is subject to various types of bacterial and other contamination if not done properly, and any food safety questions would quickly demolish the prospects for a small producer. Innovation must focus on ways of doing many of the things that large-scale food companies can do at very low cost simply because of their scale, such as packaging and assuring safety, but at a much smaller scale where the advantages of economies of scale are not as great. Small scale production and packaging must become done in highly efficient ways at a low cost. This will require research, not only in the traditional food science areas, but also developing new applications in information technology and precision manufacturing.

In addressing these issues, the University of Maine Department of Food Science and Human Nutrition and the Cooperative Extension Program are real assets to the industry in Maine providing needed expertise, R&D, testing, and technical assistance. The University operates a pilot plant equipped with food manufacturing equipment which allows for testing of food manufacturing processes and scaling up. There is also a Consumer Testing Lab which provides a much-needed resource for testing new products. It is home to a sensory evaluation lab which is the only one like it in the northeast. Cooperative Extension takes their expertise on the road to work with specialty food producers including working with home-based businesses which make up a large portion of the industry, particularly at the start-up stage.

The Maine Gourmet and Specialty Food Producers Association grew out of the Maine Food Producers Association. For a period of time, the organization was somewhat dormant, but has recently revived around specialty foods. Many small specialty-food producers are involved in this association. However, the Association has no full-time staff. As with most associations trying to bring the advantages of external-scale economies to very small businesses, it is very difficult for members to find the time to devote to association matters when the needs of their own organizations are often so pressing.

Shared Use Kitchen Coalitions have formed in five different parts of the state to collaborate on building the necessary infrastructure to support small scale food production, storage and distribution. These cooperative approaches to business development reflect the very small scale at which many of these businesses start and the challenges faced in moving from home to commercial production.

The Maine Department of Agriculture is also an important resource in helping to build a common brand identity through its "Get Real Get Maine" program. This program helps Maine food and agricultural businesses connect with customers. It also provides a comprehensive listing of sources for all Maine food and farm products, as well as lists for farmers' markets, agricultural fairs, restaurants that feature real Maine ingredients, farms and greenhouses, orchards, CSA farms, Christmas tree farms, and mail-order agricultural products. The Department also sponsors the Maine Farms for the Future Program (The program is actually administered by Coastal Enterprises, Inc.). This program provides business assistance in the form of business plan counseling and implementation grants that helps Maine farmers plan for the future of their agricultural enterprise. Many of the grants under this program have been to help farmers develop strategies to succeed in the specialty-food-products industry.

Specialty food products are also an important element in the Maine Products Marketing Program and Made In Maine program sponsored by the Maine Department of Economic and Community Development. The Maine Products Marketing Program builds recognition for Maine made products, producers, and industries. This program provides marketing assistance and sponsors the Made in Maine Website which provides details on 1,000 Maine companies that offer Maine made products. The website currently includes 193 companies in the specialty food listing.

Another important element in the growth in the Maine specialty food business is the "organic market" which addresses concerns of many consumers about the health and safety of food. The Maine Organic Farmers and Gardeners Association (MOFGA), founded in 1971, is a membership and advocacy organization dedicated to organic farming and is contracted by state government to be the entity that certifies products as organic.

The final element of Maine agriculture's innovation needs is the development of entirely new products from agriculture. The leading candidate in this area is the development of plastic polymers using potatoes. Most plastics are developed from hydrocarbons, but there is growing need to find substitutes for oil and gas as inputs simply because of their rising costs. A recent study by the University of Maine investigated this possibility specifically for Interface Fabrics, Inc., the owner of Guilford Industries (Dickinson and Rubin 2007). Guilford has long used recycled plastic materials to manufacture fabric for its line of office furniture. The study found that capacity exists for Maine potato growers to easily expand production of current varieties of potatoes that would be suitable for the production of the polylactic acid needed for Guildford's products.

The development of a major new market for potatoes would almost certainly reinvigorate that commodity and could result in the first major expansion of potato growing in more than forty years. The specific applications for Guilford are very likely only one possible application of the technology of using agricultural products as a substitute for hydrocarbons in the production of plastics.

8.2 Clusters

Knowledge and Skills Foundations

Maine is clearly a center for research and knowledge related to its forest products and agriculture industries. A diversity of knowledge and skills is strongly present in Maine, ranging from the management of land for forests and agriculture to a wide range of manufacturing and marketing skills needed to operate in a number of different lines of business across both sectors.

Cluster Status

In the 2002 cluster report (Maine Center for Business and Economic Research 2002), we found that forest products and agriculture exhibited the clearest structural characteristics of clusters. This remains the case for the major subsectors, which we redefine here somewhat to include forestry (including forest harvesting), lumber, secondary wood products, and pulp/paper under forestry. The integrated forest-products system incorporating all of these elements to make the best use of the forest resource is perhaps the most complete example of the input-output relationships that are central to clusters.

Potential Clusters	
Emerging Clusters	
Sustainable Clusters	Forest: • Forest harvesting and management • Wood products manufacturing • Pulp & Paper manufacturing Agriculture • Crop production • Dairy • Specialty Food Products

Under agriculture, the sustainable clusters include crop production and dairy. We believe that food products as a whole is well established as a sustainable cluster in Maine, but take particular note of the specialty-food-products industry. This is distinguished from the larger food products industry in focusing on specific market niches, such as organic or gourmet foods. The growth in this sector over the past two decades has been very important to the overall recent growth in food and agricultural products.

Bio-plastics may one day become a cluster, but we believe that the present levels of research and commercial activities are still too small to define it as a potential cluster. A rise in activity levels would create a potential cluster in Maine. It will take some years of commercial success to move bio-plastics into an emerging cluster.

Cluster Characteristics

- Innovation

Forest Products Innovation in the forest products industry continues in small increments that improve the productivity of lands and production processes. Forest-related research is clearly a strength for Maine. Maine also has a clear advantage in the field of engineered wood products and in composite materials incorporating wood. Substantial capacity for innovation remains in place, particularly at the University of Maine and in the diffused knowledge and skills across the industry. Major innovations in bio-fuels in development phases may provide an important new market for Maine.

Agriculture and Food Innovation continues in the growing of the state's major commodity products such as blueberries and potatoes. Like forest products, this innovation is mostly directed at improving productivity by increasing yields, lowering costs, and improving quality. A potentially important innovation is the growing of vegetables for the fresh market in large greenhouses, as Backyard Beauties in Madison has demonstrated. The specialty-food-products industry has shown a very high degree of product innovation and accounted for much of the growth in this sector.

- Regional Business Functions

Forest Products The forest products industry is among the most integrated in Maine. Not only is there a high degree of inter-relationships among all of the producing sectors, but there are substantial links to transportation and a number of other industries providing inputs to the region. It is notable, however, that almost all of the major forest products companies are headquartered outside of Maine.

Agriculture and Food The major agricultural outputs in Maine, including crops and dairy, are supported by large-scale processing, transportation, marketing, and supporting inputs. Specialty-food-product development is focused on using Maine agricultural inputs, but as this industry grows and diversifies it will probably increasingly use inputs that cannot be obtained or fully supplied within Maine.

- Entrepreneurship

Forest Products Overall conditions in the forest products industry have discouraged the growth of new small companies in forest products. But the shifts in the major forest products companies have been driven in part by significant entrepreneurship. The revival of companies like Great Northern Paper (as Katahdin Paper) and the attraction of new investors to companies like Moosehead Furniture are important examples of entrepreneurship. The dynamic market for forest products is another sign of entrepreneurship, although there are concerns that many of the sales to non-industrial owners may take forest land out of production at some point.

Agriculture and Food A very high degree of entrepreneurship is evident in agriculture as shown by the increase in small farming units and the development of the small firms in the specialty food products business.

- Financing

Forest Products For the major forest products companies operating in national markets, financing is not a specific issue. Smaller companies may face financial issues in a rising interest rate environment, but neither debt nor equity appears to be major limitations.

Agriculture and Food The new small companies in agriculture and specialty foods clearly face the traditional challenges in financing growth. An array of general support for small business development is available, as is special programs such as the Farms for Maine Future program of the Maine Department of Agriculture, but capital is likely to remain an issue.

- Relationships

Both forest products and agriculture/food are supported by a dense array of relationships within Maine. These sectors are the closest to having the networks of related and supporting organizations envisioned by cluster theory.

- Location Advantage

Forest Products Maine's advantage in forest products has always rested on the abundance and diversity of its forest resource and on the knowledge of how to use it. These remain sources of significant strength despite the many changes that have occurred in the sector.

Agriculture and Food Maine's agricultural advantages are similar to those of forest products, but recent developments that are diversifying the range of agricultural products produced and manufactured in Maine suggest an important expansion of the knowledge and skills base upon which the food sector in Maine rests.

8.3 Economic Trends

Forest Products & Agriculture: Crop, Food, & Beverage Production

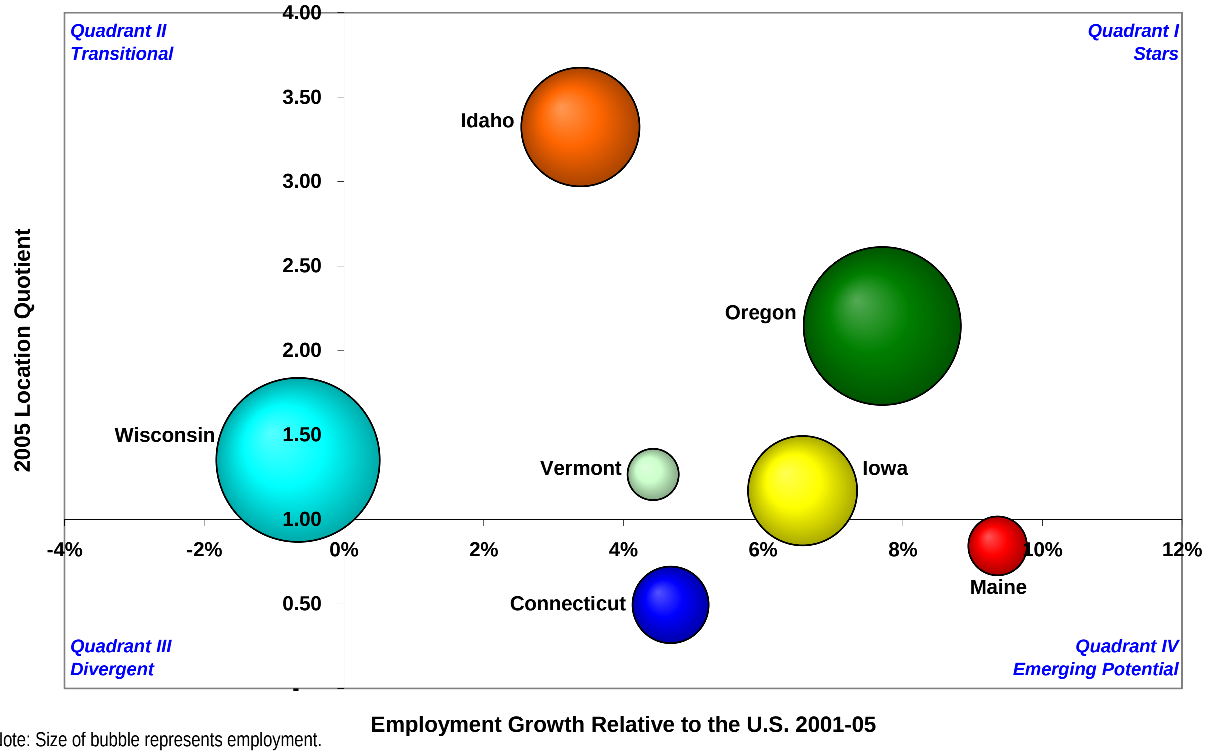
At this combined level, the Maine forest products and agriculture sector is by far the largest among those examined in this report—employing 28,338 in 2005 and spanning 1,457 individual business establishments. Because of the differing characteristics and activities of the two major component sectors, each will be examined separately in this analysis.

For information on the selection of the reference states used in the analysis, see Appendix 1.

For more detail on the employment data and analysis, see Appendix 2.

The number of crop, food, and beverage production jobs in Maine has grown in recent years, adding 6.5 percent to its base since 2001 and reaching 7,778 in total in 2005. This represents one of only three Maine technology sectors to have seen net job growth during the 2001 to 2005 period. Sector employers operate 482 establishments in the state. In Figure 27, the specialization ratio for Maine in this production sector was 0.79 in 2005.

Figure 27 Economic Trends: Crop, food, and beverage production



Note: Size of bubble represents employment.

Maine's strong job growth in the crop, food, and beverage production sector looks especially strong given an overall employment decline at the national level. In the U.S., jobs fell by 2.9 percent during the 2001 to 2005 period. The national sector declined continuously from 2001 to 2004, and held its level in 2005. For Maine, this sector experienced a decline in 2002 following the national recession of 2001, but managed to rebound quickly and added jobs at a steady pace from 2003 through 2005.

The slightly below-average (LQ), combined with a strong job growth rate, positions Maine's crop, food, and beverage production sector as an emerging one. State job growth in this industry subsector was led by gains in the beverage production sector which more than doubled (up 130 percent) to 1,041. Among the benchmark states, most have seen growth relative to the U.S. and Oregon and Idaho have highly specialized employment in this sector. Oregon has a very large and growing crop production sector and Idaho's job growth in its animal production industry has offset losses among its crop producers.

MAINE	*Total Private Sector*	*Crop, Food, & Beverage Production*
Establishments		
2001	43,232	476
2005	45,189	482
2001-05 % change	4.5%	1.3%
Employment		
2001	496,432	7,303
2005	495,554	7,778
2001-05 % change	-0.2%	**6.5%**
Average Annual Wages		
2001	$ 28,397	$ 24,923
2005	$ 32,106	$ 28,209
2001-05 % change	13.1%	13.2%
Specialization Ratio		
2001	1.00	0.76
2005	1.00	0.84
UNITED STATES		
Establishments		
2001	7,733,520	108,696
2005	8,308,128	104,325
2001-05 % change	7.4%	-4.0%
Employment		
2001	109,321,800	2,118,565
2005	110,634,500	2,058,080
2001-05 % change	**1.2%**	-2.9%
Average Annual Wages		
2001	$ 36,159	$ 27,266
2005	$ 40,499	$ 30,418
2001-05 % change	12.0%	11.6%

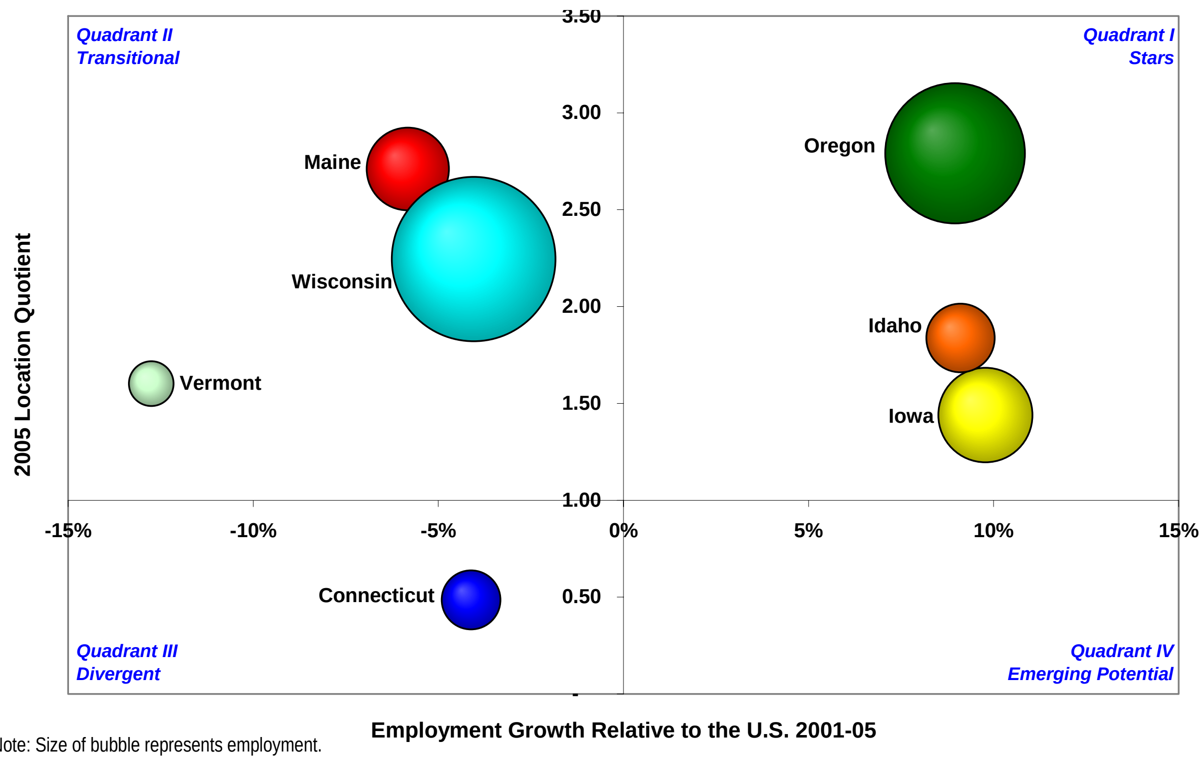
Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 23 Economic Performance: Crop, Food, & Beverage Production

Forest Products & Agriculture: Lumber, Paper, & Wood Products

The lumber, paper, and wood products sector represents Maine's largest and most specialized major industry sector. The sector employed 20,560 across 975 establishments. Relative to Maine's overall private-sector base, this high level of employment yields a location quotient of 2.71, or nearly three times the average national job concentration (See Figure 28). Despite its importance in the Maine economy, the sector is contracting both at the national and state levels.

Figure 28 Economic Trends: Lumber, Paper, and Wood Products



Note: Size of bubble represents employment.

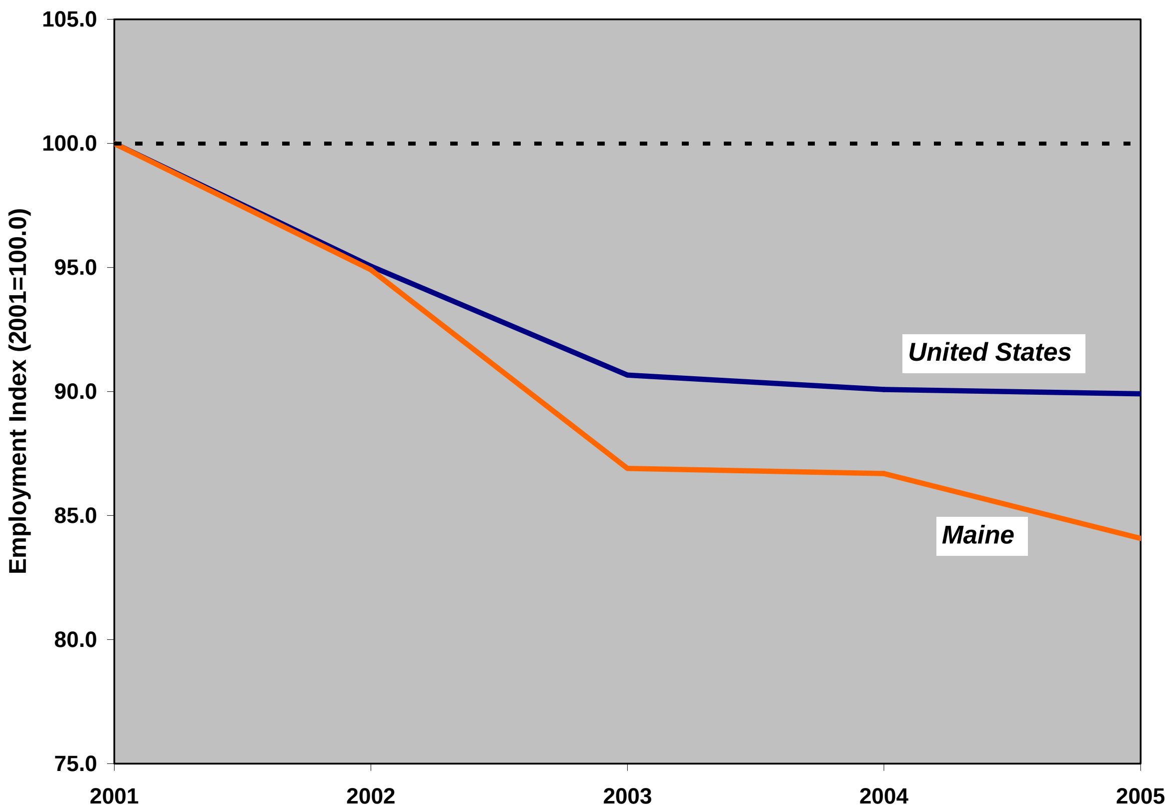
Despite some benchmark states appearance on the right side of the vertical-axis in the bubble chart, none of the benchmark states had positive job growth in the lumber, paper, and wood products sector. Those who fared better than the U.S. (lower negative growth rates) include the specialized sectors in Oregon, Idaho, and Iowa. With job losses in paper products, Oregon offset some of this decline with job gains in its furniture manufacturing sector. Similarly, Iowa also offset job losses in paper products with added jobs in wood products and furniture. A diversified sector is clearly important in these cases where one component sector (i.e. paper manufacturing) experiences a significant downturn, but the sector weathers the economic storm by growing in other areas.

Figure 29 shows that both Maine and the national lumber/wood products sector have seen similar job loss trends in recent years. Each experienced a 5 percent decline in 2002 followed by an additional 5 percent decline for the U.S. in 2003 and an 8 percent decline for Maine in that same year. Employment was relatively flat in 2004, and Maine had an additional 3 percent contraction in 2005.

Overall, employment in the Maine lumber and wood products sector is down 15.9 percent since 2001, and the national sector is down 10.1 percent.

The majority of job losses in the lumber, paper, and wood products sector in Maine has hit the state's largest component sector—paper manufacturing. The paper industry shed nearly 2,800 jobs, or 22.7 percent of its employment during the 2001 to 2005 period. Despite this labor market contraction, paper manufacturing continues to make up about half of all jobs in the sector. Though forestry and logging employment in Maine remained relatively flat (down just 1.5 percent), none of the component industries were free from job loss. Wood products manufacturing, the second largest component sector, declined by 7.2 percent; and furniture and related products saw employment decline by 24.8 percent.

Figure 29 Lumber, Paper, Wood Products Employment: Maine and US



MAINE	Total Private Sector	Lumber, Paper, & Wood Products
Establishments		
2001	43,232	1,056
2005	45,189	975
2001-05 % change	4.5%	-7.7%
Employment		
2001	496,432	24,452
2005	495,554	20,560
2001-05 % change	-0.2%	-15.9%
Average Annual Wages		
2001	$ 28,397	$ 40,014
2005	$ 32,106	$ 44,374
2001-05 % change	13.1%	10.9%
Specialization Ratio		
2001	1.00	**2.86**
2005	1.00	**2.71**
UNITED STATES		
Establishments		
2001	7,733,520	67,765
2005	8,308,128	62,248
2001-05 % change	7.4%	-8.1%
Employment		
2001	109,321,800	1,884,018
2005	110,634,500	1,693,872
2001-05 % change	**1.2%**	-10.1%
Average Annual Wages		
2001	$ 36,159	$ 34,392
2005	$ 40,499	$ 38,625
2001-05 % change	12.0%	12.3%

Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 24 Economic Performance: Lumber & Wood Products

Market Potential

Forest Products

Maine's forest products industries continue to face mature, slow-growing markets. The near-term outlook for the lumber industry is for a drop in demand because of the severe problems in the national housing market, which will suppress new home construction for at least the next two years. The effects are not as significant in Maine and New England as they are in regions such as Florida and California, but the effects will be noticeable nonetheless. The paper industry has seen steady demand in its markets for printing and related papers, but a national recession could temporarily halt this trend.

Three factors may create some additional market potential for Maine forest products. The shift towards a weak U.S. dollar will take some import pressures off and open up a variety of export opportunities that have been limited in recent years. The increasing demand for recycled paper products and for "green certified" lumber opens new markets for forest products to meet specific niche markets which are themselves getting to fairly significant size.

Agriculture

Markets for Maine's principal agricultural outputs have also been mature and slow growing for some time. Although there has been a major shift in some industries, such as potatoes, towards value-added markets like French fries, these markets have also matured. However, overall demand remains strong, and competition intense, for Maine's principal agricultural outputs.

At the same time, the food products industry is increasingly diversifying to specialty products that have high growth potential, although each product seeks to fill a specific market niche. Growth in such areas as organic and gourmet products are growing, as is the demand for locally produced food as consumers worry about food safety and quality. These changes in consumer preferences open a number of growth opportunities for Maine agriculture. The demand for locally-grown food has spawned the development of large-scale greenhouse-growing of tomatoes and potentially other vegetables using European greenhouse technologies.

8.4 Summary

Forest products and agriculture are each grounded in a very solid base of knowledge, and skills backed by extensive research facilities centered at the University of Maine. Because these sectors have been embedded in the Maine economy for so long and have achieved significant scale of operations, both forest products and agriculture contain a number of clusters that have shown they are sustainable over time.

Though still facing mature and highly-competitive markets, there are opportunities for innovation opening in each subsector which may provide new chances for growth. Some of these opportunities are variations on traditional product lines, such as the increasing market for specialized food products for niche markets (e.g., gourmet foods). Others are at the cutting edge of biotechnology as in bio-fuels and bio-plastics, which will require significant growth in Maine's research capacities.

9. Information Technology

9.1 Analysis

Of the seven technology-related sectors examined in this study, none has undergone as profound a transformation in the last three decades as information technology in terms of its impact on society. From a highly-specialized technology which was accessible to only a very few people and organizations, information and communications technologies are now literally ubiquitous. In 1970, there were less than a dozen computers in Maine. In 2003, 67.8% of households in Maine had at least one computer. This compares to 61.9% nationally, ranking Maine 9th among all states. In the same year, 57.9% of Maine households had internet access, compared to 54.6% nationally, ranking Maine 15th on this indicator. Maine was the home of the first ground station to receive satellite broadcasts (at Andover in 1961). Now having your own satellite ground station is an option available to almost every homeowner.

The implications of this revolution in information technologies[15] are profound, not least for how we must understand the role of IT in the Maine economy. In our assessment of clusters, we seek areas where Maine has unique knowledge and skills that could drive economic growth. But IT presents a challenge— How do you find uniqueness in something that is everywhere? How do you identify specialized knowledge in something we are teaching every fifth grader to use? How do we identify specialized competitive advantage when 60% of "IT" employees are employed in companies whose principal line of business has nothing to do with information technology per se.

Defining the IT sector thus requires that equal attention be paid to both product and personnel perspectives. From an output (product) perspective, the following industries (with their North American Industrial Classification System codes) are examined in the employment analysis below:

5415	Computer Systems Design and Related Services
511210	Software Publishers
516110	Internet Publishing and Broadcasting
518111	Internet Service Providers
518112	Web Search Portals
518210	Data Processing, Hosting, and Related Services

Table 25 IT Industries

These industries are primarily those which specialize in a variety of services related to the development and application of information technologies because much of the knowledge and skill base in this sector is focused on the development of these types of services. These sectors are consistent with the "software and technology services" definition of the American Electronics Association. Most studies of information technology clusters begin by identifying three major subsectors: hardware, software, and communications. The hardware side is made up of computer and electronics component design and manufacturing. For this study, however, this "hardware" side of information technologies is discussed in Chapter 11 under the precision manufacturing sector. This is consistent, we believe, with the way the definitions of information technology and precision

[15] It is more accurate to speak of "information and communication technologies" since the two are effectively integrated. Computers today do not function without access to the Internet, and cell phones are essentially microcomputers. The term "information technologies" will be used in this report to be consistent with usage in Maine.

manufacturing have evolved in Maine, which is a perspective not shared in other states. But it does represent a somewhat artificial distinction in the IT sector, so the discussion of computer and electronics manufacturing in Maine in that chapter should also be considered part of the IT story. As we note in Chapter 11, there are many opportunities for the hardware and software subsectors to better integrate with one another in Maine.

A traditional industry perspective (as in Table 25) is a limited perspective on a technology which has so thoroughly diffused in the economy. We need both an industry perspective and a personnel perspective. By a "personnel perspective," we mean that IT knowledge and skills are widely distributed throughout the all sectors of the economy and so there must also be a focus on defining IT this way. Very few organizations in Maine have biologists, but every one has somebody who has at least some computer skills.

From an industry perspective, there are about 4,500 employees in information technology. From a personnel perspective, the occupational data indicate about twice as many employees, about 8,750. These official measures, it should be re-emphasized, almost certainly understate the role of information technology in the economy. Analysis of both the industry and personnel perspectives shows that Maine is less specialized in IT than the U.S. as a whole. The analysis of industry employment data in section 9.3 shows that Maine's IT sector is at about 60% of the relative size in the economy compared to the U.S. and the analysis in Chapter 4 on occupational data shows about the same proportion for computer and mathematical occupations.

Employment on both an industry and an occupation basis in Maine has declined in recent years. The reasons for these declines are not clear, but certainly the time period of measurement involved since 2001 has influenced the trends. This was the period of the "tech bust" following the "tech boom" of the late 1990's when IT diffused rapidly through the economy and extra effort was made to update and improve systems in anticipation of the Y2K problem. The diffusion of IT skills throughout organizations may also have reduced somewhat the need for large number of IT specialists as more and more routine work is handled at the user level, for example through web-based support services.

Given the diffusion of information technologies and the skills needed to use them throughout the economy and society, it can easily be concluded that a "sustainable cluster" of economic activities related to IT exists in Maine. There is a great diversity of economic activity that is being sustained by continuous expansion and development of IT applications in every sector from health care to manufacturing to finance to tourism. But this very diversity of economic activity also makes it very difficult to speak of IT as a "cluster" in the same sense of a propulsive set of economic activities that define a unique competitive advantage for Maine.

Put another way, we need to look for IT activities that form a current or potential export activities (sales beyond Maine) rather than just serving local needs or the needs of industries whose principal line of business is other than IT, but which depend on IT for their effective functioning. An example of this distinction is the difference between DeLorme Mapping and UNUM. Both require highly-skilled IT professionals to succeed, but DeLorme's competitive success is based on its IT products, while UNUM's is based on its skills and knowledge of insurance. We also need to look at IT skills and employment that is integral to the success of Maine's other targeted technology sectors such as biotech, marine technologies, etc. Companies such as Image Works , a Portland-based "new media company," supports clients in a number of other technology sectors such as the Gulf of Maine Research Institute, Pet Health Network, MariCal, and the Gulf of Maine Observing System.

DeLorme Mapping is also an element in one of the areas that was identified in the 2002 cluster study as an emerging area of expertise in Maine: geographic information systems, or more generally geospatial analysis. This was based not only the presence of such firms as DeLorme and James W. Sewall and Company in Old Town, both national leaders in the development and application of geospatial software and applications, but also of emerging companies such as Blue Marble Geographics. Also important is the presence at the University of Maine of a unit of the National Center for Geographic Information and Analysis, a National Science Foundation-funded center for advanced research in this field. The University of Maine has a Ph.D. program in Spatial Information Science and Engineering, and GIS education has spread through almost all of the higher education institutions in Maine offering both undergraduate and graduate students the opportunity to develop skills in this area. Geospatial information systems and technologies remain a relatively small, but potentially important, emerging cluster in Maine.

There has been important growth in this field, with several startup companies being formed. An example is Intelligent Spatial Technologies, founded in 2003 with operations in Portland and Orono, which makes the iPointer, a technology which integrates GPS (geographic positioning services) with other data bases to allow users to gather information immediately about buildings, landmarks, etc. using the cell phone or other mobile platforms.

An area which has developed fairly rapidly since 2002 is the field of what is called "new media." The term covers many different types of activities, but at its core refers to the use of information technologies to display and distribute the products of artists, including visual arts such as film, music, and new ways of distributing written information such as "hypertext fiction." The field of new media is an increasingly important outlet area for the creative economy, as evidenced by the fight over the share of incomes to be paid to film and television writers from the distribution of films on DVD and over the Internet shows.

There has been a significant creative economy in Maine for some time (Colgan 2005), so the development of new media outlets that offer individual artists and creative people direct outlets to the markets is a potentially very significant change affecting the Maine economy well beyond the IT sector. Higher education has already made significant investments in teaching and research in this area. The largest program is the New Media studies program at the University of Maine, which has become a popular undergraduate major. Programs in new media related subject are also available at the Maine College of Art and at York County Community College. Rockport College, which grew out of the Maine Photographic Workshops, is now a degree-granting institution which focuses on photography and film making in the digital age.

The Penobscot Bay area around Rockport has also become the center of a very active community interested in developing a new media center in that region. A number of companies such as Pen Bay Media, Abacus Technology, Know Technology, and Blue Marvel New Media are working with the University of Maine and other regional organizations to determine how this particular branch of information technology might develop. This activity in the Midcoast region is in addition to a very active new media community in the Portland area, where the largest concentration of the creative economy is located.

There are other areas where information technology may develop specializations within Maine that are most appropriately considered as cross-cutting areas with other technology sectors. Examples include:

> **Bioinformatics** The use of computers to conduct analysis and management of the increasingly complex information emerging from genetics and other biological research is seen as a major evolution in the biomedical research field. An input to biomedical research,

it is emerging as a specialized industry in its right. The first commercial spin off from The Jackson Laboratory, Bar Harbor Biotechnology, is in the bioinformatics field. IDEXX is also undertaking significant developments in information technologies in its field of veterinary health products.

Measuring and Controlling This field is also discussed in the section of Chapter 11 on the electronics subsector of precision manufacturing. The development of measuring and controlling devices has been a particularly consistent theme in the projects submitted to the Maine Technology Institute for funding. Among grants closed up to June 30, 2007, about 10% of all MTI grants supported research in some form of measuring and controlling technology, the majority of them from firms in the environmental technologies and precision manufacturing sectors. The Laboratory for Surface Sciences Technology at the University of Maine is also a unique asset for research into sensor technologies.

These brief examples give only a sense of two areas where IT crosses over to affect other technology sectors. The ever-increasing capability of information technologies to handle higher and higher volumes of data and to communicate at faster speeds means that the demand for IT applications in virtually all technology development is without practical limit.

The future development of commercially-successful IT-based products and services in Maine will depend critically on the availability of the required workforce. This is the consistent theme communicated to us by people throughout the industries who were interviewed for this study. There is profound concern that Maine simply does not have a steady enough supply of high-quality people trained in the necessary IT skills to do the real innovative work that is needed. There are a great many IT professionals engaged in the task of keeping the existing systems working and improving the day-to-day functioning of hundreds of thousands of computers and thousands of computer networks, but a much smaller number of real innovators.

Recent trends in the labor market for IT skills and in the output of related degrees in Maine show contradictory trends. While the number of employees has been going down, whether measured by occupation or industry over 2000-2005, the number of degrees given in computer and information sciences has gone up from 63 in 1996 to 120 in 2006 (see Chapter 4). These figures on degrees do not include degrees in areas such as new media. Why then the concern about the availability of workers?

Several forces working in different directions are at work. First, the number of graduates has grown, but relative to demand it is still small. The TechMaine website routinely lists hundreds of openings each month, but Maine higher education institutions are turning out only a few hundred graduates in all IT fields each year (including areas like new media and GIS). Many of these graduates are going directly into operational employment rather than into work in development settings. Applications development positions in large firms often offer better pay and benefits than going to work for the small start-up companies that are pushing innovation in IT.

For those who want to work in really innovative environments, and to some extent for all IT professionals, the density of the labor market opportunities in Maine are simply much smaller than in neighboring New Hampshire or Massachusetts. The attractiveness of living in Maine may be very high, but the constant flux which is characterized the IT development industry through most of its history has made areas like Silicon Valley much more attractive as places for an IT career (Saxenian 1994). As with biotechnology (see Chapter 5) recruiting highly-skilled professionals from outside of Maine is still the key to finding the workforce on which innovation in IT will depend.

These issues with workforce have not gone unnoticed. There are a number of initiatives underway to try to address the need for advanced IT skills by building in the career possibilities in this field at the K-12 school level. The school laptop program has moved Maine to the second ranked state in terms of Internet connected classroom computers per student (according to Education Week's Technology Counts) and early assessments indicate that it is acting to improve learning (according to Center for Education Policy, Applied Research, & Education, USM studies). There are activities underway to link Maine's school laptops to the University of Maine/Jackson Lab super-computer initiative. TechMaine has undertaken an initiative to include develop a software testing lab and curriculum at the Westbrook Vocational Technical School and Burgess Computer is providing Morse High School Students in Bath with build-your-own computer kits.

It is also worth noting that, since the last cluster study, the importance of higher education programs to Maine's IT companies has grown and is a major issue, particularly in southern Maine. Companies that used to not even consider USM IT students and graduates are now reporting that while USM doesn't meet all their needs, it is an important source for workers and the performance of those hired from USM has been good. Industry/academic relations at USM regarding IT have strengthened through internships, scholarships, training, and recruitment efforts. This raises significant concerns among the industry as recent financial troubles at USM and what is perceived as a continued lack of coordination between USM and the University of Maine on computer science offerings raises concerns about southern Maine's future workforce adequacy.

The density of the labor market raises another issue that is similar to biotechnology: the problems of trying to organize clusters of economic activity in a very geographically dispersed region. There are centers of IT around the University of Maine-Bangor region, in the Portland area, and one perhaps emerging in the western Penobscot Bay area. Smaller groupings may be found around Augusta, but the distances are still great. Educational and training programs such as certification for network engineers are offered in only a few places; York County Community College is the only community college campus offering certification in Cisco networks.

It is true that, in some sense, IT is its own answer to the distance problem, but not the whole answer. The availability of bandwidth and high-speed communications needed to sustain a highly innovative information technology sector remains much patchier through much of the state than those interviewed desire to see. Nor are there easy answers to these problems as the controversy over the acquisition of Verizon's land lines by FairPpoint Communications shows.

Despite the distances involved, the IT sector has demonstrated a very solid capability to create and sustain formal and informal networks and relationships. TechMaine, which was originally the Maine Software Developers Association (MESDA) has emerged as an important resource which has very diligent in finding ways to create and sustain networks for IT professionals to interact with one another. The organization is reaching beyond the traditional functions of a trade association to establish a software testing lab modeled on similar facilities at Stanford and Carnegie Mellon universities. The lab, to be located in Westbrook, will be an industry-education partnership offering both learning opportunities for students and an important development resource for industry. There are also IT networks which have formed around the University of Maine and the Target Technology Incubator in Bangor, and the efforts to build a new media focus in the Pen-bay region is emerging from a very energetic network of public- and private-sector organizations.

9.2 Clusters

Knowledge and Skills

The diffusion of information technologies throughout the economy means that, in one sense, the diffusion of skills to use IT is perhaps the most widespread technical knowledge in Maine. There are numerous education programs in IT available throughout the state, none more emblematic than the laptop programs in schools. The more important question is whether there are sufficient advanced skills in this technology to drive innovation and create new commercially-successful ventures. Here the picture is more limited, as there are relatively few students in computer science programs and only a small number of areas where there is sufficiently specialized knowledge to form the basis for a cluster.

Clusters

Defined solely by the presence of knowledge and skills, information technology represents a cluster that is present throughout the Maine economy. But this very characteristic makes it very difficult to identify a role for IT that is sufficiently unique that it can be said to be distinct advantage for Maine. Such clusters must be found within more specialized areas of IT that are carving out distinct roles for Maine-based information technology innovation that appear to have real market potential both within Maine and outside of the state. Our analysis suggests that four areas of specialization might fit within our definitions of clusters:

Geospatial technologies is an emerging cluster with a strong research base at the University of Maine and spreading expertise at other campuses of the University of Maine System and a number of commercially-successful companies, ranging from start-ups to relatively large companies with established markets.

Potential Clusters	New Media Bioinformatics Measuring & Controlling Technologies
Emerging Clusters	Geospatial Technologies
Sustainable Clusters	

New media, bioinformatics, and measuring/controlling applications are all potential clusters. Each has a knowledge/skills and innovation base as well as the beginnings of a set of commercially-viable firms. Each is very small, very new, and still somewhat diffuse and unorganized, so it is premature to identify them as anything more than potential cluster that may develop over the next decade.

It should be noted that the very large size and diversity of IT activities in Maine means that there are probably still other potential clusters of specialized activity that may form with time. These should by no means be considered the only areas where IT may develop.

Cluster Characteristics

<u>Innovation</u>

Innovation in information technology is very spread out between the private-sector firms, many of them start-ups or still at very young stages. However, it is noteworthy that research in this area does not show up as a major strength in the analysis in Chapter 3. To be sure, the measures used in that analysis are not suited to assessing the kind of research and development that takes place in the small software development firms or in new media. But its absence does suggest a different role, at least in quantity, for the higher-education research base than in other sectors.

Regional Business Functions

Because the development of IT is so labor intensive, the key input from within the region is the workforce. Maine has made strides in improving the supply of skilled IT professionals, but it appears to still be well short of demand even in an environment where total employment has not been growing. The IT sector as a whole, and particularly the parts that strive to be the most innovative, must still rely heavily on recruiting workforce from outside the state.

The efforts by TechMaine to establish a software testing laboratory, similar to those found in other IT innovation centers and to provide services similar to those with the Advanced Engineered Woods Composite Center at the University of Maine is an important step in expanding the in-state capabilities to support innovation in this sector.

Entrepreneurship

The sector is characterized by a very high rate of entrepreneurship. This is evident, not only in the presence of a great diversity of many small companies with a diverse array of technologies and products such as Quantrix (an Excel substitute) and CrossRate (a GPS technology), but the growth of companies such as DeLorme and the transformation of the James W. Sewall Company, founded in 1880, into a national leader in the field of geospatial technology services. Technical barriers to entry in this field are low, but the financial and organizational barriers to entry and growth are similar to other sectors. It is relatively easy to start a company and relatively difficult to grow it.

Financing

Financial barriers to entry remain a key concern for many of the younger companies, particularly in making the critical expansion moves required to go from proven start-up to significant expansion of product lines and markets. The availability of venture capital, a frequent source of financing for this transition, is an issue for this sector as it is for other sectors in Maine. Venture capital investors, still smarting from the tech boom/bust of the 1990's, remain much comfortable with investments in Massachusetts or New Hampshire than in Maine. Nevertheless, 18 Maine IT companies have attracted a total $147 million in venture capital investments since 2000. TechMaine has a proposal to expand on this success by seeking state approval of a "Fund of Funds" to encourage more private investment in the state for technology companies.

Relationships

Despite the distances involved in forming and sustaining networks of organizations and people, the information technology sector has developed and is developing effective networks in several regions of the state. These appear to have been successful in providing opportunities for "knowledge spillovers," but distance is still a barrier to the growth of networks.

Location Advantage

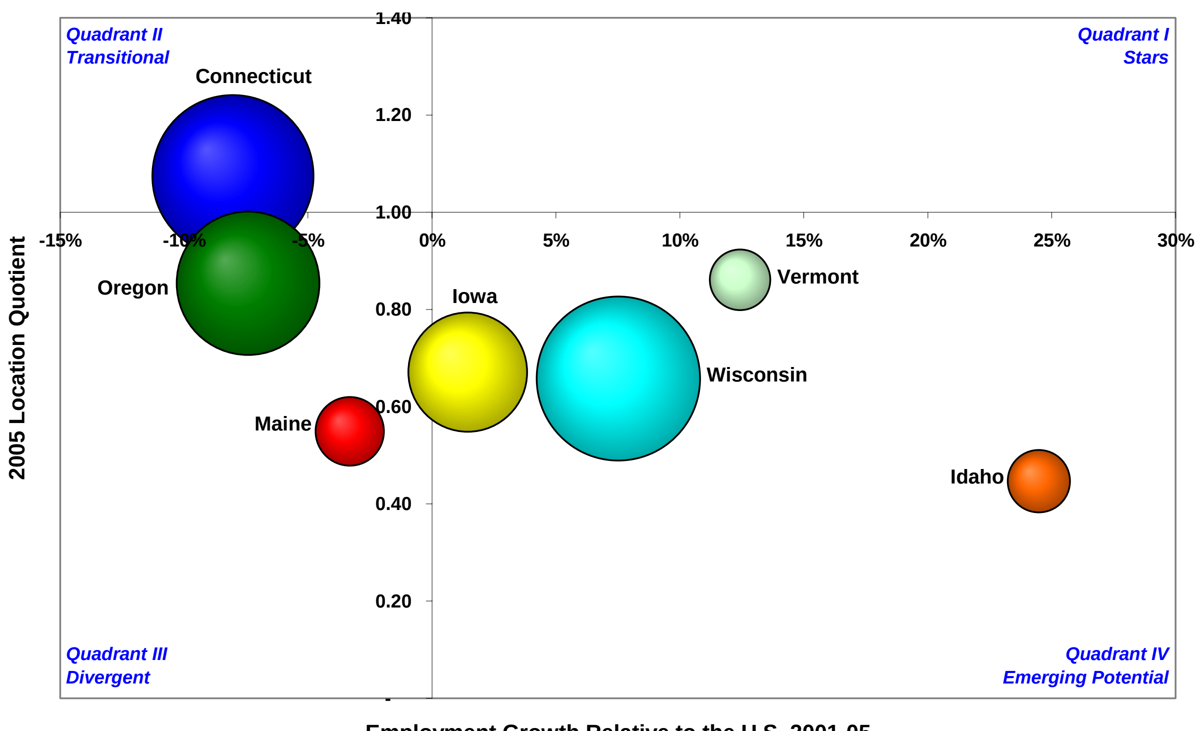
The relatively-low technical-barriers to entry in this sector mean that activity can take place almost anywhere, but tends to aggregate where there is a combination of workforce and organizational density. Maine is building both, but still lags behind other major IT regions. Maine does not self supply a major portion of the innovation-oriented workforce and must recruit a significant proportion of the workforce from out of state. Its location advantage is built on innovative ideas, a thin labor market, and the ability to meet the quality-of-life expectations of a very mobile workforce. Interviews for this study repeatedly emphasized this point. It is clear that Maine does have many of the attributes that this workforce is seeking, which is greatly to our advantage. But the same interviews also indicated that the core of research, education, and training which would make Maine a center of information technology development *primarily* on the basis of the knowledge and skills generated here is not yet present.

9.3 Economic Trends

> For information on the selection of the reference states used in the analysis, see Appendix 1.
>
> For more detail on the employment data and analysis, see Appendix 2.

Maine's information technology sector employs 4,542 among 882 state business establishments. Similar to the national IT sector, job totals reached a peak in 2001 before falling off during the two years that followed. On net, Maine's sector job totals fell by 14.6 percent over the 2001 to 2005 period and the national sector lost 11.2 percent of its jobs. The encouraging trend, however, is the national and state rebound in the sector that took place during 2004 and 2005 (See Figure 30).

Figure 30. Information Technology Employment, Degree of Specialization, and Growth Relative to the U.S. 2001-2005



Note: Size of bubble represents employment.

Within the broad information technology cluster, the majority of jobs in Maine are in computer systems design and related services where more than 3,000 were employed in 2005. This represents about two-in-three state IT jobs, about the same share as the national IT sector. Workers in this component industry are engaged in computer programming and software design, testing, and implementation. Like many regions around the country, Maine experienced job losses in this key driver of the larger IT industry which is down by 17 percent in the state since 2001. Again, though, the encouraging trend is the jobs added in 2004 and 2005 which hopefully points to a growing sector once again.

None of the benchmark states in this study can be considered to be specialized in the information technology sector. Connecticut has the highest specialization ratio of the group at 1.07 for 2005. Idaho, which has an IT cluster of similar size to Maine, has seen positive net growth in the sector since 2001 (up 13 percent). Like the national structure, Idaho has a majority of jobs in systems design and related services, which has grown since 2002. Idaho has also seen job growth in smaller component industries like software publishing and internet publishing.

MAINE	***Total Private Sector***	***Information Technology***
Establishments		
2001	43,232	773
2005	45,189	882
2001-05 % change	4.5%	14.1%
Employment		
2001	496,432	5,316
2005	495,554	4,542
2001-05 % change	-0.2%	-14.6%
Average Annual Wages		
2001	$ 28,397	$ 41,808
2005	$ 32,106	$ 51,333
2001-05 % change	13.1%	22.8%
Specialization Ratio		
2001	1.00	0.56
2005	1.00	0.55
UNITED STATES		
Establishments		
2001	7,733,520	187,939
2005	8,308,128	184,951
2001-05 % change	7.4%	-1.6%
Employment		
2001	109,321,800	2,079,337
2005	110,634,500	1,845,622
2001-05 % change	**1.2%**	-11.2%
Average Annual Wages		
2001	$ 36,159	$ 76,313
2005	$ 40,499	$ 81,291
2001-05 % change	12.0%	6.5%

Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 26 Economic Performance; Information Technologies

Market Potential

The market for information technologies is effectively unlimited in size, but that does not mean that is without periodic variation. Following the tech boom of the late 1990's, the early part of this decade was the tech bust, the effects of which are still observable in the employment data above, and during which the information technology industry experienced severe cut backs. In the last three years or so, the industry has reached a plateau in which major technologies like personal computers and cell phones have now reached essentially commodity status. Design and some assembly work is done in the U.S. or Europe, but most of the manufacturing takes place in Asia. The U.S. is still the world leader in software for the personal computer, but the days of the "killer app" in the sense of a program like Excel or Word which is loaded onto millions of computers are largely over.

The dominant theme of the future for the market for the software and services side of information technology is likely to be the development of a very wide variety of both hardware and software products to meet increasingly specialized applications. Such applications may still have thousands of customers worldwide, making the economic potential for even small companies potentially quite large, especially given the low costs of distributing software over the Internet. This is where the Maine information technology industry's strengths lie. There is a clear advantage to industry development along these lines, as there are many niches to fill. But there is a disadvantage in that if the best opportunities are in highly-specialized applications, the size of markets may be limited. IT-led development will have to rest on the successes of many small companies and a relatively small who grow to medium-sized companies.

9.4 Summary

Information technologies and the knowledge and skills associated with them are so widely diffused in the economy that one must look for more defined areas of specialization in order to identify potential clusters of competitive advantage. Maine has developed a specialization in geospatial technologies that is an emerging cluster, and there is evidence that technology development in new media, bioinformatics, and in the application of IT to measurement and controlling technologies are potential clusters. Future growth in IT in Maine is likely to depend on identifying and effectively filling a variety of niche application development for specialized users. The markets for individual niches may be small but the overall potential is large.

A solid base of research and education in computer and related technologies exists in Maine, but it does not emerge as research strength in the analysis of research outputs. The workforce is the key to development of this sector because of the relatively low technological barriers to entry. It does not appear that Maine's higher education institutions are producing graduates near industry demand, and that industry growth is heavily dependent on recruiting a workforce from out of state.

10. Marine Technology and Aquaculture

10.1 Analysis

This sector, as defined by the Legislature includes aquaculture, including both shellfish- (oysters and mussels) and finfish- (primarily Atlantic salmon) production that is already widespread along the Maine coast plus the development of new cultured seafood. Aquaculture is a well-defined sector. Marine technology is a more complex area, including non-profit educational and research institutions and manufacturing enterprises that support from marine-related scientific research. Each group has developed largely independently of the others, though there is a substantial amount of aquaculture-related research at some of the research institutions such as the University of Maine. Each has its own history, its own central institutional motivations and its own challenges for future growth. Each of the subsectors needs to be considered on its own to determine to what extent the characteristics of clusters may be found in this sector.

Aquaculture

Commercial-aquaculture production—finfish raised in pens in the open sea, shellfish raised on rafts and in cultivated beds in coastal estuaries and trout/baitfish raised in hatcheries and pools—is a significant industry in many coastal communities in Maine. A recent study conducted for the Aquaculture Innovation Center estimates that the current direct sales value of finfish aquaculture in Maine total approximately $22 million and that of shellfish aquaculture approximately $3 million. Together these enterprises support approximately 500 jobs (Planning Decisions Inc. 2007).

Finfish aquaculture production has declined precipitously over the past several years because of price pressures brought by world-wide expansion; the consolidation of major producers; the spread of disease from the Canadian provinces to Maine; a rash of bad publicity about the environmental impacts of pen feeding; and conflicts among aquaculture, residential, and recreational users of coastal waters. At the same time, shellfish aquaculture sales have more than doubled over the past eight years.

The central knowledge key to this industry's growth lies in marine-related animal husbandry and in the broad field of oceanography. These two fields focus on the biological and physical processes needed to culture marine food organisms on a commercially-viable scale. That knowledge is quite different for finfish and shellfish, but the central challenge is the same for both subsectors: increasing productivity is the key to industry growth.

For example, for oyster growers in Maine today, every 1 million seed oysters yield between 300,000 and 400,000 commercially-saleable oysters. The central challenge to Maine growers is to gradually increase this yield. In effect, improved cultivation techniques could double or even triple industry sales from the existing natural capital stock. Similar increases could be made in finfish cultivation. The challenge is to determine the right combination of food, disease resistance, adjustments to changing water temperatures/chemical properties, together with labor any physical and financial capital, to increase the amount of saleable product.

Maine's aquaculture industries have access to a significant research capacity in these fields and also benefits from a good flow of tacit information among a relatively small community of growers which are geographically concentrated in two parts of the state. The research capacity includes a number of researchers at the University of Maine School of Marine Sciences, including activities at the Orono campus and at the Darling Center in Walpole and at the Center for Cooperative Aquaculture Research in Franklin. There is also a small private-sector research and development industry in Maine focused on bringing ideas from the larger biotechnology-research areas to aquaculture. The Portland-based firm MariCal, is an example of this additional research capacity. MariCal has brought developments in the manipulation of proteins to aquaculture applications, and was a larger generator of patents from 2002-2007 than the University of Maine (see Chapter 3).

The subsector also benefits from relatively-close geography proximity. Finfish aquaculture is located primarily from Penobscot Bay eastwards where deep water and high tidal flows provide the most ideal conditions for this type of activity in the eastern United States. As these conditions exist from Penobscot Bay into the Bay of Fundy, salmon aquaculture is an important activity throughout this region, and Maine's finfish aquaculture industry is tightly integrated with that of New Brunswick. A New Brunswick firm, Cooke Aquaculture, is now the major owner of production and processing facilities in Maine. On the other hand, shellfish aquaculture is primarily located from Penobscot Bay westward to the southern mid coast areas of Lincoln County.

The strong research and knowledge base for aquaculture in Maine contrasts with other relationships among the industries, government, and the public. Concerns regarding the environmental effects of pen feeding salmon and conflicts about the visual and recreational impacts of salmon pens and shellfish floats have diminished public support for the industry. Many industry participants argue that there is an "unnecessarily adversarial" relationship between aquaculture growers and state regulators. Information about lease sites (actual and potential) and communication about measures leading to the closure of clam flats and the banning of shellfish sales are subjects of concern expressed by growers.

Worldwide and U.S. seafood demand remain strong. Maine's favorable growing conditions put its aquaculture industry in the position that most producers can sell all their output. Over the long term, however, as the industry grows, developing a "Maine" brand will become increasingly important because the world supply of cultured fish is growing and prices, particularly for salmon, have been subject to long-term declines as output has grown from such regions as Chile and Scandinavia. The skills of knowing how to identify and sell to all possible customers are beyond what most small producers now possess. Gaining those skills will be necessary if the industry is to reach its potential. There is also a growing need to address concerns about the environmental impacts and nutrition values of farm-raised salmon in particular (Reel 2007). The development of a distinct brand and addressing the concerns of sustainability and environmental impact are major challenges facing salmon aquaculture worldwide.

Marine Research & Education and Related Technologies

A 2005 report by the University of Massachusetts identified five sectors in what that study termed the "marine science and technology industry in New England":

- Marine Instrumentation and Equipment
- Marine Research and Education
- Marine Services
- Marine Materials and Supplies
- Shipbuilding and Design

Of these sectors, "marine instrumentation and equipment" and "marine services" comprise a group which best fits what Maine has called "marine technology". These groups include firms and organizations involved in development and manufacturing oceanographic and geophysical measuring instruments, acoustical equipment for sensing and imaging, and marine electronics plus services such as software design meant to support these activities. "Marine research and education" in the Massachusetts study is consistent with the same sector defined above for Maine. Shipbuilding and Design encompasses the specialized ship building for the Defense Department done at BIW, Portsmouth Naval Shipyard, and Electric Boat.

	Marine Instrumentation & Equipment	Marine Services	Marine Materials & Supplies	Marine Research & Education	Shipbuilding & Design	Total
Maine	28	7	150	184	10,404	10,773
Connecticut	524	339	524	2	8,000	9,389
Massachusetts	4,470	2,687	679	1,027	0	8,863
Rhode Island	5,179	1,223	278	119	145	6,944
New Hampshire	2,295	53	464	126	0	2,938
NEW ENGLAND	12,496	4,309	2,095	1,458	18,549	38,907

Table 27 Marine Technology Employment in New England

In the field of marine research and education, Maine is home to an impressive array of institutions including:

- University of Maine System
    - University of Maine School of Marine Science:
        - Maine Sea Grant Program
        - College of Marine Science at Orono
        - Ira C. Darling Center, Walpole, Maine
        - The Center for Cooperative Aquaculture Research, Franklin
    - University of Southern Maine Aquatic Systems Research Institute
    - University of Maine at Machias

- Other Educational Institutions
    - University of New England, Marine Science Center
    - Maine Maritime Academy
    - Coastal Studies Program at Bowdoin College
    - Environmental Studies programs at Bates and Colby colleges
- Private Non-profit Research Organizations
    - Bigelow Laboratory for Ocean Sciences
    - The Maine Aquaculture Innovation Center
    - Mount Desert Island Biological Laboratory (MDIBL)
    - Cobscook Bay Resource Center
    - Downeast Institute for Applied Marine Research and Education
    - Penobscot East Resource Center
    - Gulf of Maine Ocean Observing System (GoMOOS)
    - Gulf of Maine Research Institute (GMRI)
- Government Agencies

- Wells National Estuarine Research Reserve
- Maine Department of Marine Resources
- Maine Department of Inland Fisheries and Wildlife
- U.S. Department of Agriculture

Evidence of the strength of marine research among these institutions is that the Division of Ocean Sciences in the National Science Foundation is the largest division within NSF funding research in Maine, and marine biological research comprises one of the "mega clusters" of research specialization in the analysis of Maine's research capacity with strong records in both grants and publications (see Chapter 3).

Moreover, Maine's marine research institutions are well embedded in a broader array of marine research organizations in New England and eastern Canada. A good example of these relationships is found in the Gulf of Maine Ocean Observing System (GOMOOS), an independent organization which actively monitors the physical, chemical, and biological conditions in the Gulf of Maine. This effort, part of world-wide effort to create an integrated ocean-observing system, is a partnership among research organizations in Maine, Massachusetts, New Hampshire, New Brunswick, Nova Scotia and New Jersey.

The range of research undertaken in the marine field in Maine is quite broad, ranging from very basic investigations of fundamental physical and biological processes to highly applied research of immediate use to industries from aquaculture to shipping. Like the research capacity in biotechnology (see Chapter 5), the marine research capacity represents a strong foundation of knowledge and skills, but the development of commercial products from this base is more limited. Aquaculture and commercial-fisheries-related research are the most obvious links between the research base and commercial activities.

Since 2004, the Maine institutions—together with several for-profit private enterprises—have joined forces to form the Maine Marine Research Coalition (MMRC). The goal of the MMRC is to develop marine research capacity leading to job creation and technology transfer potential. The Coalition has been an important player in the development of research bond issue proposals and in campaigning for their approval by voters. It has also demonstrated progress in setting state-wide research priorities and in expanding collaborative efforts among institutions. In part, this is the result of the disparity in size between the dominant institution (The University of Maine) and the others and, in part, it is the result of the natural focus of all non-profit institutions on the demands of their funding sources.

Despite the relatively large volume of marine research in Maine, there has been relatively little development of commercial ventures to develop technologies related to marine research in Maine, as has developed in other marine research centers such as Massachusetts. This can be seen using data from the 2005 UMASS study (see Table 27). The UMASS study used surveys of over 400 firms in New England to identify those firms that specifically serve marine-related markets, which offers a more precise view of these industries than is available from standard government data sources which focus on products or services provided rather than markets served.

Using this approach, and including ship building and design, Maine has the largest marine technology employment in New England. But 97% of that employment is at BIW and the Portsmouth Naval Shipyard. Maine is actually the smallest state in terms of employment in marine instrumentation/equipment and in marine services. Rhode Island is the leading supplier in these industries, largely because of the Naval Undersea Warfare Center which makes up the bulk of employment in that state. Leaving this defense-related facility aside, Massachusetts has the largest marine instrumentation/equipment and marine services industries, largely driven by connections to the marine research centers there, particularly the Woods Hole Oceanographic Institution and MIT. It is this connection between research and technology development that Massachusetts has succeeded in cultivating, but Maine has not.

To be sure, there has been commercial technology developments in Maine connected to marine research. Fluid Imaging is an example of a company which has taken the technologies and products originally developed as a result of marine-related research at the Bigelow Laboratory into entirely different markets. Another example of technology evolving directly from marine research is the evolving and expanding array of technologies related to the integrated ocean observing systems. These technologies include both direct-sensing devices, such as those deployed on buoy systems, and remote-sensing technologies employed on satellites. Maine researchers have contributed knowledge to the development of these technologies, but the principal design and fabrication of these various systems does not take place in Maine.

Recent developments in marine research, in which Maine has played an important part, provide a potential path for commercial technology development. Current efforts in the U.S. and elsewhere to create an Integrated Ocean Observing System (IOOS) are driving new generations of direct and remote sensing technologies to permit continuous monitoring of physical and biological oceanographic conditions. The ocean observing system, of which the Gulf of Maine Ocean Observing System (GOMOOS) headquartered in Portland is an important center, is made possible by advancements in a variety of technology fields. Because the observing system is envisioned as a global system deployed over the next two decades in all world's oceans, it represents a potential major market for marine technology development. This development would be a growth opportunity for the measuring and controlling technologies noted as potential growth industries under both information technologies and precision manufacturing-electronics.

One major change has occurred in this subsector compared with the situation when the previous cluster study was undertaken concerns Bath Iron Works. At the time the earlier study was done BIW was engaged in a substantial amount of research and development work on behalf of the Department of Defense. Under the Clinton Administration, DOD policies encouraged large defense contractors to manage research and development related to their areas of production. Under this policy, BIW directly engaged in a substantial level of research effort on subjects ranging from wearable computers to the use composite materials in ship construction. Under the Bush Administration, however, these research and development efforts have been recentralized within the Pentagon. The net effect has been that BIW, which was viewed as a major potential contributor to the development of marine technologies in Maine in the earlier study, conducts virtually no R&D today that is not directly related to its principal lines of business. This has been a significant loss to the potential of developing a much larger marine technology industry in Maine.

10.2 Clusters

Knowledge & Skills Foundation

For aquaculture, the central skills required combine animal husbandry and marine skills. This is a relatively unusual combination and presents potential problems for aquaculture producers in the future. For the moment, skill shortages do not represent a critical bottleneck for the industry because the key to immediate growth is increasing the productivity of existing operations. The more technical, research-based, knowledge key to the industry's growth involves identifying the most productive locations in bays and estuaries to site growing operations and identifying better ways to circulate nutrients so as to enhance animal growth.

For marine technologies, particularly instrumentation, the critical knowledge and skill sets rest in a combination of physical and biological oceanography and in fields such as satellite sensor design, telecommunications network development, computers and software, and electronics. Maine is well positioned in the first set of knowledge/skills and has the general knowledge and skills in electronics and information technologies for the second set of ingredients, but these have not been applied in marine settings in Maine to anywhere near the extent that they have been in Massachusetts.

Clusters

Aquaculture exhibits sufficient characteristics of a distinct knowledge and skills base in Maine, a commercially-viable product, and links to suppliers and customers in Maine that it can be characterized as a cluster. Aquaculture has already gone through several cycles of growth and contraction while remaining a key economic activity in several areas of coastal Maine, and so it appears to be a sustainable cluster.

Potential Clusters	
Emerging Clusters	
Sustainable Clusters	Marine biology/ oceanography/ husbandry related to aquaculture

Marine research and education is clearly a major activity in Maine, but commercial developments from that research are still sporadic and small in scale, despite being individually impressive in their sophistication and success. Commercial product development in the marine instrumentation and equipment and marine services industries will have to intensify if a cluster is form in this sector.

Innovation

Maine's aquaculture producers have been engaged in a process of continuing innovation since they were first established in the 1970's and 1980's. Operators have continually sought the best sites for pens, rafts and beds, testing nutrient-feeding systems and water circulation systems. The aquaculture industry in Maine exhibits a strong combination of scientific research and tacit knowledge (the practical experience gained from daily operations) upon which successful clusters depend. Maine has clearly been a leader in marine research and education, although commercial innovations outside of aquaculture have not reached the same scale as in aquaculture.

Regional Business Functions

Aquaculture is deeply integrated into the Maine economy. Supplies consist of construction materials, fuel, electricity, repair services and feed. Marketing involves distribution relationships to markets largely centered in the Northeast.

Entrepreneurship

Aquaculture is a highly entrepreneurial industry. Most participants are owner-operators and have spent years identifying, acquiring and establishing lease sites. The finfish sub-sector has gone through a major shake out with the closing of the operations of several large international firms. Cook Aquaculture of New Brunswick has established a Maine operation that has shown great promise, and new ventures in halibut production hold significant promise for the future. If aquaculture is to extend beyond the traditional salmon and shellfish markets, it is likely that a new generation of entrepreneurs similar to those who established the industry in Maine in the 1970's and 1980's will be required.

Financing

Because of the decline of salmon production over the past several years (as well as the negative publicity accompanying that decline), traditional financial institutions view this sector as extremely risky and often politically unpopular. As a result, operations tend to be small and self financed.

Relationships

The Maine Aquaculture Association has served the industry effectively for many years, maintains close connections with its members and provides numerous opportunities for sharing technical and business-related information. The industry does not feel as well served by state government. Several members of the industry have said that the single greatest obstacle to future growth of the industry is the adversarial nature of state regulations, with respect to both lease siting and environmental measurements/controls.

Maine's marine research and education institutions are well integrated in the larger marine science community, particularly in New England and eastern Canada. The Gulf of Maine is recognized as a distinct region for oceanographic research, Maine's activities are clearly at the center of those efforts. Research projects routinely involve scientists from Maine institutions and other institutions from throughout the world.

Within Maine, the Maine Marine Research Coalition (MMRC) has begun the process of representing Maine's research institutions as a whole. Its efforts have largely been focused on internal organization and lobbying in Augusta. Its greatest potential for strengthening the cluster lies in establishing greater collaboration among its member institutions, particularly around the issue of sharing institutional resources and setting common research agendas. Substantively, several members spoke of the need to bring research scientists, engineers and business product development specialists together in common locations to stimulate greater interchange and innovation.

Location Advantage

The central location advantage Maine enjoys is its adjacency to the Gulf of Maine, one of the most diverse ecosystems on the planet. At the same time, the dispersion of research institutions and commercial operations across the state makes the daily, face-to-face interactions that would exist were the enterprises that comprise this cluster located in a single location more difficult. The Gulf of Maine Research Institute has explicitly designed its new building with a large common atrium with many small gathering places to encourage both resident and visiting scientists to meet informally outside their laboratories as an expression of the need to continually foster and improve connections. Those connections are particularly important as numerous research scientists spoke of the desirability of conducting research "on the boundaries between disciplines rather than precisely within the clearly-defined boundaries of a single discipline" (as seems to be required of most funding sources). This ability to make connections across disciplines is a possible source of location advantage in Maine for marine research and technology development as it is in biotechnology (see Chapter 5).

10.3 Economic Trends

Recent History

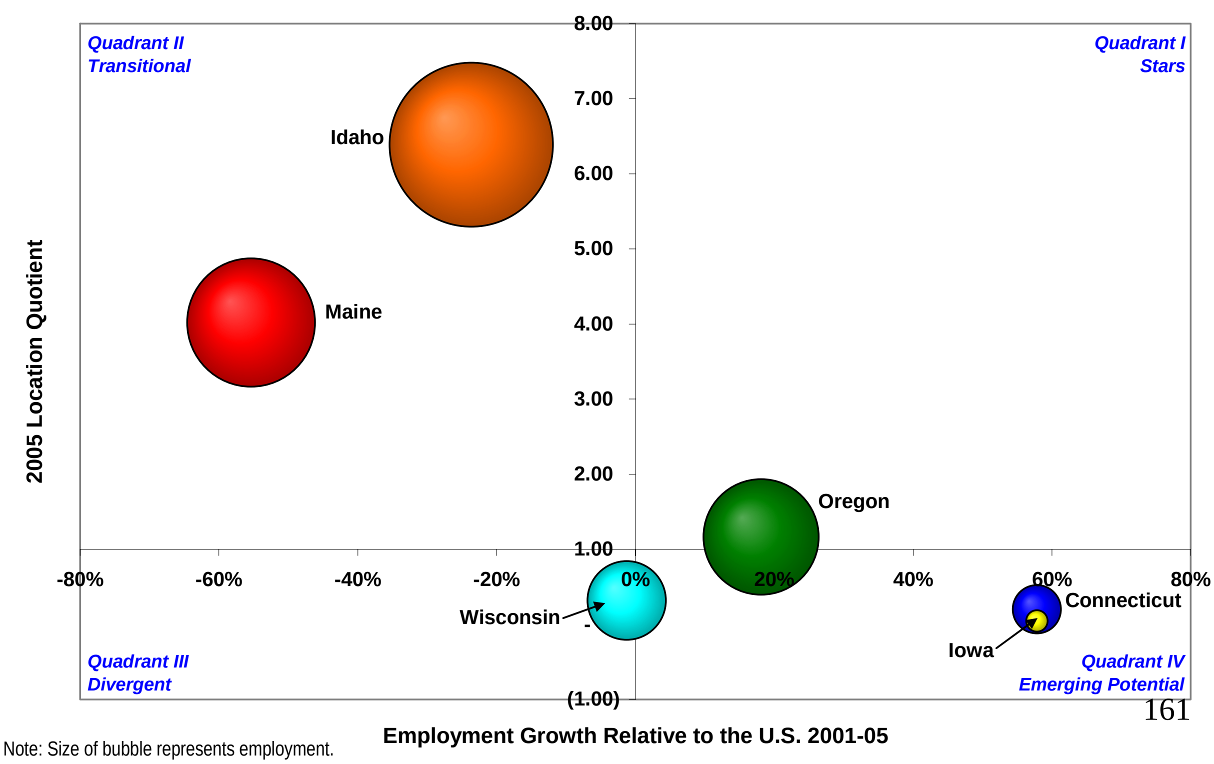
> For information on the selection of the reference states used in the analysis, see Appendix 1.
>
> For more detail on the employment data and analysis, see Appendix 2.

Because the UMASS study measured the marine technology sector for only one year, it is not possible to look at trends in that part of the sector. Clearly ship building and design will depend entirely on federal policies, not only on the procurement of the products of BIW and use of Portsmouth Naval Shipyard, but also on the extent to which any research and development may take place within those organizations. The marine instrumentation/equipment and marine services industries cannot be measured using standard data sources (the UMASS study used custom surveys), so trend data on that subsector are not available for Maine.

Measurement of employment change in aquaculture also presents difficulties. Measured as employment reported by employers, the aquaculture industry is relatively small in the U.S. Nationally, the industry employs just fewer than 6,000 across 737 business establishments. In both Maine and the U.S., however, there is a large proportion of self-employment in this industry which is not reported in the wage- and salary-employment data used here. Maine's proportion of self employment is higher than the U.S. Therefore, this analysis should be interpreted cautiously.

Nevertheless, in Maine, the 106 jobs in this sector are enough to highlight a specialized state industry. The state specialization ratio in aquaculture is 4.02 for 2005 meaning Maine's relative concentration of aquaculture jobs is four times the national average. Though the number of state jobs is down since 2001, this represents a small, but key, cluster for the state (see Figure 31).

Figure 31 Economic Trends: Aquaculture



The U.S. aquaculture industry experienced a 7.8-percent employment decline from 2001 to 2005. The two largest aquaculture states in this study (and the only two with more than 100 employed in the industry)—Idaho and Maine—both shed jobs over this same period. While both are considered to be specialized in terms of concentration of regional jobs, both states face a sector in transition as they have gone through a recent contraction. While Figure 31 shows rapidly growing sectors in Connecticut, Iowa, and other states, one should use caution in interpreting these as significant given their extremely small employment bases.

MAINE	*Total Private Sector*	*Aquaculture Industry*
Establishments		
2001	43,232	27
2005	45,189	18
2001-05 % change	4.5%	-33.3%
Employment		
2001	496,432	288
2005	495,554	106
2001-05 % change	-0.2%	-63.2%
Average Annual Wages		
2001	$ 28,397	$ 29,375
2005	$ 32,106	$ 30,943
2001-05 % change	13.1%	5.3%
Location Quotient		
2001	1.00	**9.93**
2005	1.00	**4.02**
UNITED STATES		
Establishments		
2001	7,733,520	758
2005	8,308,128	737
2001-05 % change	7.4%	-2.8%
Employment		
2001	109,321,800	6,386
2005	110,634,500	5,886
2001-05 % change	**1.2%**	-7.8%
Average Annual Wages		
2001	$ 36,159	$ 23,652
2005	$ 40,499	$ 27,427
2001-05 % change	12.0%	16.0%

Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 28 Economic Performance: Aquaculture

- Market Potential

Demand for seafood remains very strong. An old saying in the fishing industry that "every fish has a home" remains true, and population and income growth, together with innovations in retailing and food services, are continuing to expand the number of "homes" for fish. The severe pressures on wild, or "capture" fisheries has dramatically reduced the supply of fish at the same time as demand for fish has been growing. Aquaculture has been seen for many years as an important way to fill this gap between supply and demand, but intense global competition plus the technical challenges of environmentally-sustainable finfish-aquaculture have restrained the growth of salmon aquaculture. Shellfish aquaculture has shown stronger growth, but the markets for it are not as large as for salmon. Culture of other fisheries, particularly very highly-valued ground fish species such as cod and haddock, is still in its infancy, but could be a major market opportunity if commercially viable means are found.

The market potential for marine technologies is strong because of the growth in ocean-observing systems and the increasing need to develop information about oceans and marine environments to deal with issues such as climate change. Commercial technologies related to these markets are already being aggressively pursued in other regions such as Massachusetts, and represent an opportunity for Maine.

10.4 Summary

Aquaculture exhibits the characteristics of a sustainable cluster. The markers for its products are strong and could grow significantly given the world's demand for seafood and the severe pressures on capture fisheries. It is a technically-complex industry which still faces a number of challenges in mimicking the functions of natural ecosystems to grow and sustain organisms, but a robust research and skills base exists in Maine to meet these challenges.

Marine research is strong in Maine, but commercial-technology developments emerging from that research have lagged behind other states. The strength of the research foundation in Maine, together with growth in demand for technologies related to ocean observing and measurement over the next decade means that clusters may yet emerge from this sector.

11. Precision Manufacturing

11.1 Analysis

The precise definition of the "Precision Manufacturing" sector remains elusive. As it has been defined in practice, it has rested on traditional manufacturing skills in the fabricated metals and electronics industries. Like Forest Products and Agriculture (see Chapter 8), the two sub-sectors are only loosely related with one another and so require separate discussion. The inclusion of electronics, particularly the large semiconductor manufacturing facilities in South Portland, raises another definitional quandary in that so much of the electronics business is now essentially integrated within the information technology sector. We categorize the electronics manufacturing with precision manufacturing because it is based on similar knowledge/skill sets in the areas of designing, shaping and assembling complex, finely-detailed materials. We might characterize the base knowledge and skills in this area as "making products to extremely precise standards and tolerances."

The differences between metal products and electronics arise from the inputs of metal, plastics, silicon, etc. and the size of the enterprises involved. In both sub groups, there are a small number of world-scale producers—National and Fairchild Semiconductor in electronics and Pratt & Whitney in metal products—and a larger number of smaller, largely locally-grown, firms. The larger establishments are part of their own corporate global networks while the smaller firms are forever striving to make and then strengthen whatever links they can make to the global manufacturing supply chain. Both orientations tend to force managers in Maine to look outside Maine for their customers. This history has led to a myriad of separate intra-corporate and customer-supplier relationships rather than a densely-interconnected Maine-based network of relationships.

Metal Products

Many of Maine's metal manufacturing businesses were created and grew as suppliers and job shops for the larger machinery businesses of southern New England and the largest of Maine manufacturers, notably the forest products and ship-building industries in Maine. The skills of the machinist were employed to make a wide variety of products, often in relatively small quantities to meet the needs of specific customers at specific times. Examples include machining, fabrication, casting, metals finishing, mold making, engraving, and similar operations. The Pratt & Whitney plant in South Berwick, on the other hand, came to Maine in 1979 as part of its parent (United Technology) company's expansion of its jet engine production. Its production is determined by the parent company's overall corporate strategic decision making, and it benefits from the full range of skills and technical assets available through all of United Technology's various divisions.

This subsector has been shrinking in Maine. As detailed in Section 11.3, the fabricated metals/machinery industries have declined in employment by more than 16% during 2000-2005, although there were very small gains in 2004 and 2005 compared with the previous year. Their relative specialization has declined from .59 to .57, and Maine has lagged significantly behind the rest of the U.S. and the reference states. Part of the problem facing this subsector is declines in overall manufacturing activity, which reduces the demand for the products of this intermediate goods industry. Closure of paper mills and the reduction in ship-building activity at Bath Iron Works or Electric Boat have shrunk the customer base. At the same time, competitive pressures from foreign suppliers such as China have greatly increased.

The technical knowledge and skills that are the foundations of this subsector reside largely in the workforce and the firms. There are training programs in machine tools at Eastern Maine, Central Maine, Northern Maine, Southern Maine and Kennebec Valley community colleges, but the output of these programs has been falling (see Chapter 4). This is illustrative of a larger workforce issue facing the subsector. There has also been concern expressed by industry firms for a number of years about the lack of an adequate workforce for the industry despite the availability of well-paying jobs. An important reason for this is the clash between the changing technological basis of the industry towards integration of sophisticated information technologies into the materials shaping and fabrication process using equipment such as numerically-controlled machine tools, and the basic math skill sets of younger workers. There is also a clear perception issue. Younger workers clearly perceive the decline in industrial jobs and question the desirability of committing themselves to a career in that field. This is similar to the problem facing forest products and agriculture discussed in Chapter 8.

Research in the metal products industry is primarily undertaken at the firm level. The small size of most of the firms in this industry limits the amount of research that is undertaken, although it is notable that the analysis in Chapter 3 does identify modest strength in patent activity related to this sector.

Metal products is served by the Manufacturers Association of Maine, formerly the Maine Metal Products Association, as well as the Maine Chapter of the Society of Manufacturing Engineers. These two organizations perform traditional trade association functions. The Manufacturers Association also links to national programs such as the National Institute of Metalworking Skills to expand and improve training for the industry.

The decline in traditional markets in Maine and New England is forcing metal products firms to search for new markets. To expand to new markets, firms will have to adapt in two ways. First they will have to adapt to the technical needs and specifications of other manufacturing industries. This may include changes in both workforce training and the acquisition of new capital equipment. An example of a possible new market is the aviation/aerospace industry. The Maine Manufacturers Association has undertaken an examination of the prospects for expanding into this market, and there have MTI grants in support of product development for the aircraft industry.

Beyond the technical demands of new markets, metal products firms must find ways to fit into the supply chains of their customers. This has always been the case with this industry, which provides intermediate goods for other manufacturers, but the demands on manufacturing industries are much greater. Just-in-time logistics systems put a premium on timing and coordination with transportation systems. Customers have much higher expectations about services that will accompany the parts, as well as much greater expectations of quality. Mastering the techniques of quality assurance and quality control is increasingly critical. All of these elements combine to allow a seamless fit into complex supply chains with very high-quality products. The ability to make these kinds of commitments to customers is critical in establishing a competitive advantage over possible import competitors.

The Pratt & Whitney plant mentioned above is a leading example of precision manufacturing in Maine, but it is also the largest representative of the aerospace and aviation field in Maine. The development of aviation related economic activity (aside from traditional air transportation) has also been boosted by Telford Aviation, a major service company for aircraft maintenance. We did not find sufficient evidence of connections among aviation related activities in Maine to designate this area as a potential cluster, but the announcement that Embry Riddle Aeronautical University, the world's largest university devoted to aviation and space, will expand its services as part of the redevelopment of the Brunswick Naval Air Station after the Navy's departure along with the Regional Development Authority's plans for making facilities available to the aviation industry will serve as the foundation for what may become a cluster in the future.

Electronics

The electronics industry in Maine is essentially divided into two major subsectors. The largest firms are Fairchild Semiconductor, which has both its corporate headquarters and one of its principal fabrication facilities in Maine, and National Semiconductor which also has a fabrication facility. These firms are part of the global electronics industry, producing semiconductors for electronic equipment markets around the world. The output of National Semiconductor is almost all shipped to Malaysia where it is incorporated in many different products then shipped to Europe, Asia, and back to the U.S.

At the other end of the scale, Maine has approximately 50 companies employing approximately 1,000 people making a wide range of electronics, communications, navigation, medical, and control devices. These range from full-service contract manufacturers such as Saunders Electronics in South Portland to small companies and start-ups seeking to develop products for specific niche markets.

Maine electronics has, like other manufacturing sectors, seen a sharp drop in employment in recent years. The "tech bust" of the early years of this decade took a heavy toll on Maine, with nearly a 40% decline in employment and a drop in specialization from .73 to .59. Maine lagged substantially behind all of the peer states in employment growth over 2001-2005 (see Section 11.3).

The two semiconductor fabrication facilities in Maine operate at the leading edge of electronics product design and manufacturing. Both South Portland facilities are part of world-wide network of production and design facilities owned by the two companies. National Semiconductor has a Design Center for Custom Solutions located at its South Portland facility. Fairchild Semiconductor conducts both customer-oriented and basic-research at its South Portland facility. Fairchild is the leading recipient of patents in Maine (see Chapter 3).

Both National and Fairchild have internalized what for smaller and less mature companies are inter-industry cluster relationships into their own corporate structures. They each have on line "universities," company-sponsored training programs available on line, columns, blogs, chat rooms where customers and company engineers can interact to tinker with products to better meet customer need. Their labs combine scientists, engineers, and product-development people in the same space interacting. In 2006, National equipped all 8,500 employees worldwide with 30-gigabyte video iPods to be used as a training and communications tool. Electronics Weekly presented National with the "Investing in People" Award acknowledging the company's effective engineering development program.

But research in electronics extends well beyond Fairchild Semiconductor. Of the patents examined in Chapter 3, 29% are in fields related to electronics, as Table 29 (which is extracted from Table 9 in Chapter 3) shows.

Communications: radio wave antennas	24
Electricity: electrical systems and devices	22
Miscellaneous active electrical nonlinear devices, circuits, systems	18
Data processing: measuring, calibrating, or testing	17
Wave transmission lines and networks	17

Semiconductor device manufacturing: process	14
Active solid-state devices (e.g., transistors, solid-state diodes)	11
Multiplex communications	11
Data processing: generic control systems or specific applications	10
Electrical connectors	10
Oscillators	10

Table 29 Patent Classes Related to Electronics and Number of Maine Patents

The data in Table 29 also show a connection between the electronics industry and the measuring/controlling subsector discussed in Chapter 9 on information technology. This is an important connection because it represents the closest link between the electronics and information technology sectors in Maine. As noted, this connection is typical of many other areas where software and hardware development are the core of the IT sector.

However, the two semiconductor firms do not appear to have close ties to the rest of the Maine economy in either material inputs or outputs. Maine is an important location for semiconductors because of historic ties, very large sunk capital costs, and workforce. However, interviews indicate that much of the highly-trained research and engineering workforce comes from out of state (similar to the situation in biotechnology and information technology).

The electronics industry is supported by education programs in electrical engineering at both the University of Maine and University of Southern Maine. However, there do not appear to be formal networks or strong informal networks supporting the industry. Some members of the Maine Manufacturers Association are in the electronics industry, but that association is not specifically oriented towards the electronics industry.

11.2 Clusters

Knowledge & Skills Foundation

Technical knowledge and skills in the metals processing and electronics fields are critical and are widely distributed in the firms in these industries. Particularly for metal products, the skill to effectively fit into complex supply chains for their customers is becoming more and more important. One other knowledge/skill that both require is a relatively high level of mathematical sophistication. The precision fabrication processes employed in both industries, though greatly aided by applications of information technologies, still requires a much higher level of math than most other jobs in Maine. As the chronic problems hiring machinists in metal products indicates, this requirement may be a source of weakness for this sector.

Cluster Status

Both metal products and electronics are difficult to assess as clusters in the sense used in this analysis. Both are clearly industries that are well established commercially in Maine, with long histories in both cases. As a result, there is a strong workforce base with the requisite knowledge and skills to be innovative and commercially successful. Both have some connections to higher education, and both have active research and development activities, although there is a very clear edge in

Potential Clusters	
Emerging Clusters	
Sustainable Clusters	Design, shaping, coating, and composing materials of metal, silicon, plastics, etc

this category in the electronics industry. R&D in technical innovation is largely contained within the firms themselves, and there is little in the way of knowledge spillovers occurring.
Networks in metal products appear moderately strong through the Maine Manufacturers Association, but weaker for electronics.

At the same time, backward (supplier) and forward (customer) linkages to other parts of the Maine economy do not appear to be strong in either case. Most of the technology and inputs for both sectors must come from out of state. Forward linkages to Maine are a little stronger. The metal products industry still serves other customers in Maine's manufacturing sector, and the electronics industry is increasingly connected in information technology to develop measuring and controlling products for a variety of applications.

In sum, these characteristics are consistent with being sustainable clusters, but there are weak linkages at some key points. Networks and connections within Maine could be strengthened in both supplier/customer relationships and, perhaps, in research and development outside of the firms themselves. Electronics equipment manufacturing which have measuring and controlling applications and developments in information technologies is an example of a linkage which, if strengthened, would also bolster the cluster effects of this sector.

Cluster Characteristics

- Innovation

  Innovation in this sector lies primarily in the private firms. Particularly in electronics, there appears to be very active research and development going on in the firms as evidenced by the number of patents emerging from the sector. The sector includes the single largest recipient of patents in Maine, National Semiconductor. For the major suppliers, innovation consists of working with customers to improve existing products. For the semiconductor industry, it consists largely in finding ways to reduce size, weight, and power consumption. For machinery manufacturing (Pratt & Whitney), it consists largely in finding ways to lower greenhouse gases emitted from airplane engines, finding lighter structural materials and developing advanced combustion concepts.

Another aspect of innovation critical to this sector applies to business processes rather than technologies. Competing with other sources of electronics requires reorienting businesses to provide a high level of service along with quality products.

- Regional Business Functions

With some exceptions, both metal products and electronics in Maine operate in the middle of the production process. Unlike, for example, forest products which buys the vast bulk of its raw material inputs from within Maine, the material inputs for these industries largely comes from outside the state. Many customers of metal products are still in state, but the electronics industry's customers and increasingly those of metal products firms must be found out of state. The Maine Manufacturers Association's efforts to expand markets in the aeronautic/aerospace markets will, if successful, find customers primarily outside of Maine.

The notable exceptions include the two semiconductor firms. Fairchild Semiconductor not only has one of its fabrication facilities in Maine, but also its corporate headquarters. This is one of the very few companies with worldwide operations headquartered in Maine. National Semiconductor also conducts an important part of its corporate research in Maine.

- Entrepreneurship

There is little evidence of entrepreneurship in the form of new start-up companies in metal products. The number of establishments in this industry has been constant or declining for some time. In contrast, the number of establishments in electronics has grown modestly, suggesting some level of entrepreneurship. At the same time, entrepreneurship in the form of research and organizational changes appear to be relatively strong among existing firms. The larger firms have not been the source of spin-offs because of the high technical and capital barriers to entry.

- Financing

Given the strong history of many of the companies in this cluster, financing is not a major problem.

- Relationships

The Manufacturers Association of Maine (and its predecessor organization, the Maine Metal Products Association) has over 250 members. It has become increasingly active in promoting public awareness of the viability of manufacturing as a source of high-paying jobs in Maine in an attempt to overcome the drumbeat of negative publicity about the "decline of manufacturing." Its newly established Business Growth Services division is attempting to address the need for organizational modernization, and its industry education support programs attempts to provide opportunities for members to familiarize themselves with current production techniques and quality verification standards. However, no similar organization exists specifically for the electronics industry.

Though trade association relationships, particularly in metal products, are strong, forward and backward linkages in this sector with the rest of the Maine economy are much weaker than in other similar industrial sectors in Maine. This is one of the weakest cluster characteristics for these subsectors.

- Location Advantage

Maine's location advantage is the same as any other region's—the skill of its labor force and the responsiveness of its business organizations. Given the increasing importance put on being able to fit into global time-sensitive supply chains, there has been concern expressed about Maine's location relative to transportation (which is generally good) and to other points in the supply chain. For example, some metal products firms have encountered difficulties in getting timely service from metal-heat-treating facilities outside Maine. Even if the Maine producer has met its deadlines, it cannot meet its delivery commitment because of bottlenecks further along the supply chain.

11.3 Economic Trends

Recent History

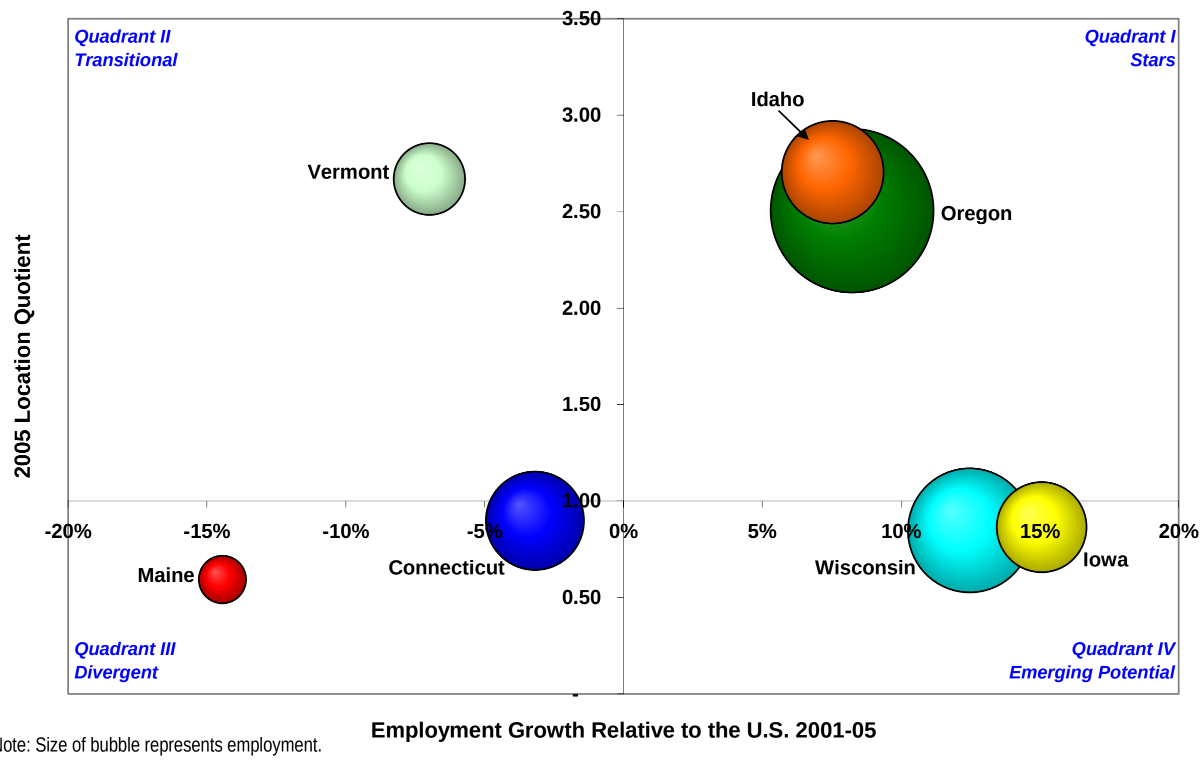
Computer & Electronics

Maine's computer and electronics manufacturing sub-sector, like the national industry, has experienced substantial job loss since its employment peak in 2001. In 2005, the state sector employed 3,479 workers, down 40 percent from nearly 6,000 jobs in 2001. Similarly, national computer and electronics manufacturers cut 25 percent of all jobs during the 2001 to 2005 period. Unlike the U.S. sector, Maine has added to its base of total business establishments from 58 to 66 during this same time period. This gain in the number of establishments is encouraging despite the overall job losses as it may indicate strength among some smaller, more entrepreneurial in-state operations. Maine's location quotient measured 0.59 in 2005, which indicates a significant under-representation of jobs within the state (See Figure 32).

For information on the selection of the reference states used in the analysis, see Appendix 1.

For more detail on the employment data and analysis, see Appendix 2.

Figure 32 Economic Trends: Electronics



Note: Size of bubble represents employment.

Reflecting the weakness in the computer and electronics manufacturing sector following the 2001 recession, all of the comparison states profiled in Figure 10 had net job losses. While the majority of job losses occurred in 2002 and 2003, many of the states continue to lose jobs through 2005. The exceptions have been in Iowa, Wisconsin, and Oregon which have each seen some jobs added in both 2004 and 2005. Iowa and Wisconsin experienced a 6 percent and 5 percent employment gain in 2005, respectively. Oregon has a highly-specialized employment base in computer and electronics manufacturing with a specialization ratio of 2.51. Idaho and Vermont are also highly specialized (specialization ratios of 2.70 and 2.67, respectively), but both have seen jobs erode steadily since 2001. One positive note about the employment picture in electronics is that separations (layoffs) have been declining steadily since 2001, while the number of new hires has remained constant.

MAINE	*Total Private Sector*	*Computer & Electronics Mfg.*
Establishments		
2001	43,232	58
2005	45,189	66
2001-05 % change	4.5%	13.8%
Employment		
2001	496,432	5,767
2005	495,554	3,479
2001-05 % change	-0.2%	-39.7%
Average Annual Wages		
2001	$ 28,397	$ 44,445
2005	$ 32,106	$ 61,315
2001-05 % change	13.1%	38.0%
Specialization Ratio		
2001	1.00	0.73
2005	1.00	0.59
UNITED STATES		
Establishments		
2001	7,733,520	22,374
2005	8,308,128	19,689
2001-05 % change	7.4%	-12.0%
Employment		
2001	109,321,800	1,749,403
2005	110,634,500	1,308,039
2001-05 % change	**1.2%**	-25.2%
Average Annual Wages		
2001	$ 36,159	$ 64,667
2005	$ 40,499	$ 77,112
2001-05 % change	12.0%	19.2%

Source: Battelle analysis of BLS QCEW data from IMPLAN.

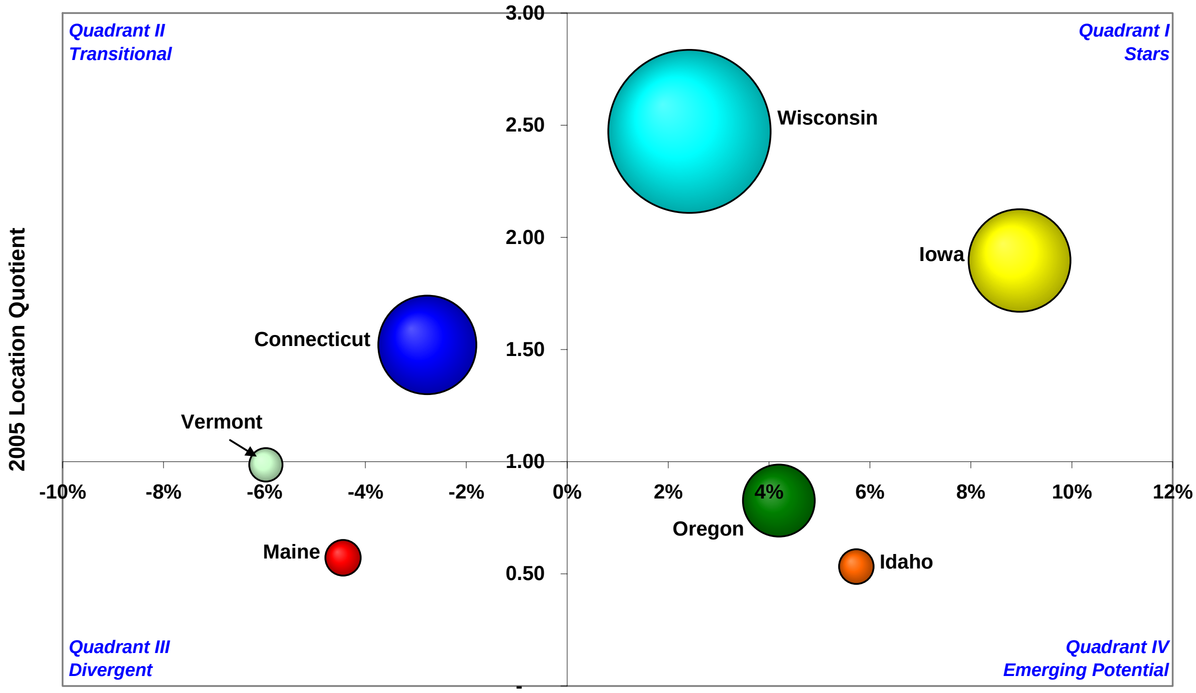
Table 30 Economic Performance: Computers & Electronics

Manufacturing: Fabricated Metals & Machinery

Further reflecting overall weaknesses in both the national- and state-level manufacturing sectors during the early- to mid-2000's, are the significant employment declines for the fabricated metals and machinery industries. Nationally, industry employment fell by nearly 12 percent during the 2001 to 2005 period and Maine had a 16-percent job loss. Fortunately, small job gains in 2004 and 2005 helped to offset some of these losses.

The majority of Maine's 6,846 sector jobs are within the fabricated metal product manufacturing component (68 percent of total jobs), a slightly greater share than the national split (57 percent). In fabricated metals, Maine recorded 2 percent and 1 percent employment gains in 2004 and 2005, respectively. Overall, total firms operate 337 business establishments in Maine. The state LQ is 0.57 (see Figure).

Figure 33 Economic Trends: Fabricated Metals and Machinery



Note: Size of bubble represents employment.

Similar to the computer and electronics industries, Maine and all comparison states had net employment declines in fabricated metals and machinery during the 2001 to 2005 period. Unlike the computer and electronics cluster, though, a majority of states have added jobs in 2004 and 2005, perhaps signaling a real labor market turnaround in the cluster.

Wisconsin employs, by far, the largest group of workers in the cluster, with more than 140,000 in 2005. Its employment base is nearly a 50-50 split (51 percent of jobs are in fabricated metals). Wisconsin's cluster is highly specialized with about two and a half times greater employment concentration than the national average (LQ is 2.47). Iowa, though it has not regained all of its job losses since 2001, has been growing at a steady pace, and since 2003 has added more than 5,000 jobs. The majority of Iowa jobs (and recent job growth) in this industry are in its large-machinery manufacturing sector.

MAINE	Total Private Sector	Fabricated Metals & Machinery Mfg.
Establishments		
2001	43,232	359
2005	45,189	337
2001-05 % change	4.5%	-6.1%
Employment		
2001	496,432	8,167
2005	495,554	6,846
2001-05 % change	-0.2%	-16.2%
Average Annual Wages		
2001	$ 28,397	$ 37,261
2005	$ 32,106	$ 41,988
2001-05 % change	13.1%	12.7%
Location Quotient		
2001	1.00	0.59
2005	1.00	0.57
UNITED STATES		
Establishments		
2001	7,733,520	99,581
2005	8,308,128	91,850
2001-05 % change	7.4%	-7.8%
Employment		
2001	109,321,800	3,028,992
2005	110,634,500	2,673,565
2001-05 % change	**1.2%**	-11.7%
Average Annual Wages		
2001	$ 36,159	$ 40,962
2005	$ 40,499	$ 46,655
2001-05 % change	12.0%	13.9%

Source: Battelle analysis of BLS QCEW data from IMPLAN.

Table 31 Economic Performance; Fabricated Metals & Machinery

Market Potential

Markets for the major products of this sector such as semiconductors and jet engine parts, are relatively mature and slow growing. The markets' demand for the many different types of manufactured products that are made with inputs provided by the Maine metal products industry is variable, but overall is also slow growing. Niche markets in electronics and metal product specialties may grow quickly, but are also likely to be small.

Better connecting electronics and metal products with other sectors and clusters in Maine may provide one way to boost the economic development effectiveness of growth in these industries.

11.4 Summary

The precision manufacturing sector comprises two distinct subsectors: metal products and electronics. Each has a small number of very large world-scale firms and a much larger number of smaller companies serving a variety of customers, primarily outside Maine. The electronics sector shows high rates of innovation as measured by patents. Innovation capacity rests primarily within the private sector, though higher education institutions provide some support. Knowledge spillovers and networks within the subsectors appear to be relatively low.

The large firms in each subsector have weak supplier/customer relationships within Maine. These are somewhat stronger for smaller firms, but still weak overall. While the subsectors may be considered sustainable clusters, the links within Maine are a noticeable weakness as a cluster. The economic development potential of this sector for Maine may be improved if this sector can develop closer relationships with other clusters, as for example, in measuring and controlling technologies.

12. Conclusions and Recommendations

12.1 Findings

A review of the trends affecting Maine's technology sectors over recent years shows a very mixed picture of growing strengths in research and development combined with lagging economic performance. Questions are raised about whether the human resources needed to grow a technologically innovative economy are present.

1. Maine has made real progress in spurring research and development, the creation of innovative new products, and the establishment of networks of organizations in each sector that can support and enhance development and growth. Supporting infrastructure has improved in all sectors. Maine has also developed very distinctive and identifiable areas of research strength, many of which can also be linked directly to economic activity in the state.

2. Economic performance among the sectors measured as employment growth over 2001-2005, has been mixed when compared with the United States and with a representative group of other states. Maine has fared comparatively well in biotechnology, composites & advanced materials, and in crop, food & beverage production. Employment growth in other sectors such as forest products, alternative energy and engineering services, fabricated metals, and information technology has lagged behind the U.S. and peer states. While output growth may have continued in some sectors and product lines even with employment declines, the result still indicates very difficult competitive positions for many industries.

3. In the key area of human resources, Maine lags significantly behind the U.S. and peer states in the presence of many key STEM (science, technology, engineering, and mathematics) occupations within the economy. From 1996-2006 Maine decreased employment in computer and math occupations, while these occupations were growing nationally. Employment in engineering and technician occupations declined in Maine at a much faster rate than in the U.S. While there was employment growth among scientific occupations in Maine, it was at less than half the national growth rate.

Together, these trends suggest real potential for Maine to develop a technologically innovative economy, but that potential is yet unrealized. The concept of "clusters" is key to realizing that potential because clusters speak to the way that human resources, knowledge, financial capital, and institutions are combined to define *regional* as opposed to *individual* competitive advantage.

The term "clusters" has become so widely used that its meaning has become confused and lost great value as a guide to choosing sensible actions. Clusters are best thought of, as Chapter 2 explains, as the *mix* of ingredients which allows a set of knowledge and skills developed and maintained within a region to create sustainable economic activity. Clusters are defined by those knowledge and skills that comprise the interactions necessary to create commercially successful economic activity. Those interactions were illustrated in Figure 2 in Chapter 2 and are reiterated here:

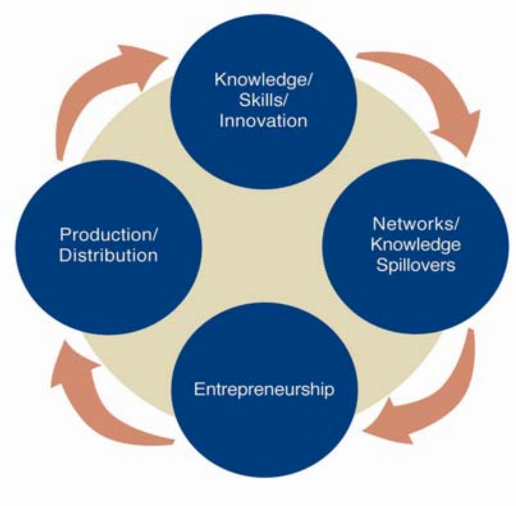


Figure A

Figure 2 Cluster Elements

The focus on knowledge and skills is essential because products change over time. The products from Maine's forests have changed over more than a century from lumber to pulp & paper to engineered wood products to perhaps making fuels to replace petroleum. But all of these products rest on a base of expanding knowledge and skills about how to grow and use trees.

It is very important, therefore, not to confuse clusters with the products that result. This is not easy. Products are the most visible aspect of clusters. They are what we can see, while the knowledge and skills behind the products remain largely invisible. Moreover, products are the way in which almost all data are organized. When we go to examine a concept like "composites and advanced materials," we find no industrial classification for it. We must infer the presence of the requisite skills in other data.

In this report we have sought to look behind the product-based numbers as much as possible to identify the underlying knowledge and skills base that is sufficiently anchored to, and unique to, Maine. Thus, whatever changes in the economy occur, Maine will be in a good position to forge new products and services that will sustain prosperity in the state. This idea about Maine, as innovator, inventor, and at the leading edge of meeting the demands of a global economy is new, but it is consistent with the "asset based" approach to economic development recommended by the Governor's Quality of Place Council in their first report (Quality of Place Council 2007) and the Brookings report (Brookings Institution Metropolitan Policy Program 2006).

Since this is a transformative period in Maine's economy, the development of clusters will take place unevenly. This is particularly so because in those technology-oriented sectors which we have been charged to examine there is enormous diversity. Biotechnology is still a very young field in Maine, though growing rapidly. Forest Products and Agriculture are, with fishing, the oldest industries in Maine. We cannot use a single idea of a cluster to describe this diversity. Rather we need to recognize that clusters are at various stages of evolution in Maine. For that purpose, we have defined three different types of clusters:

- Potential Clusters

  A distinct set of knowledge and skills exists within Maine, but associated commercial activity is weak. Organizations associated with the knowledge and skills (public, private, and nonprofit) are identifiable and have at least some form of interrelationship with one another. Knowledge and skills are largely confined within the organizations and not yet widely shared among them. Institutions tend to remain separate and collaborate only on an occasional basis and for very limited purposes.

- Emerging Clusters

  A distinct set of knowledge and skills is generating measurable commercial activity in Maine. Sharing knowledge across organizations is becoming increasingly important to the success of the organizations both individually and collectively. Commercial success is seen as increasingly dependent on the relationships among organizations within Maine. Collaboration among institutions is intermittent but increasingly seen as routine and necessary for success.

- Sustainable Clusters

  A set of knowledge and skills that meets all the tests of an emerging cluster and has been shown, over time, to produce sustainable levels of economic activity that are driven by continuous innovations The innovations are in a large part, the products of the network of organizations and people that make up the cluster. Institutional collaboration is recognized as essential for all parties.

In making these distinctions, we are proposing a shift in focus from the perspective in the 2002 Cluster Study. In that study, we assessed what we now call the technology sectors on the basis of their cluster characteristics. For some sectors, such as composites and advanced materials or forest products/agriculture, this approach continues to have utility. But it is clear that in other sectors, the sector as a whole cannot be meaningfully defined as having sufficient coherence and cluster characteristics to be useful In these sectors we must seek possible cluster characteristics at a finer level of detail.

We also ignore the somewhat artificial boundaries imposed by the technology sector definitions. Many of the clusters we identify have no clear home in any of the sectors as usually defined. The emergence of whole new types of products from wood may be classified as biotechnology or forest products. Much of the advances in biological research is being driven by information technology, which itself permeates every industry. The sectors, variously defined by both inputs and outputs, are an imperfect guide to Maine’s innovation potential and its clusters.

	Knowledge/Skills	Current Economic Activity	Economic Activity
Potential Clusters	Biomedical research	Improved medical treatments	Therapeutic products
	Bioinformatics	Informational analysis products and services for genetic research	Expanded research activities
	Measuring and controlling devices	Diverse electronic and other products	Integrated software/hardware approaches to measuring and controlling
	"New Media"	Diverse services for a variety of industries	Same
	Creating "green products"	Diverse	Diverse
Emerging Clusters	Genetics/genomics	Biomedical research	Same
		Products serving biomedical research	Same
	Antibodies and diagnostic materials/processes	Diagnostic materials	Same
	Geospatial analysis/GIS	Diverse	Same
Sustainable Clusters	Developing new materials by combination of dissimilar materials or finding new applications for existing materials	Boat building, construction materials, piping, fluid control and filtering systems	Renewable energy equipment, military and transportation equipment
	Chemistry and chemical engineering	Pulp and paper, other chemicals	Wood-based fuels, plastics and other products
	Marine biology/oceanography/ husbandry related to aquaculture	Cultured fish and shellfish	Same
	Forest harvesting and management	Pulp and paper, lumber and wood products	"Sustainable Forestry" certified products
	Design, shaping, coating and fabricating materials of wood, metal, silicon, plastics, etc.	Pulp and paper, lumber and wood products, metal products electronic products	Same
	Crop and soil sciences	Commodity and specialty food products	Oil-replacing products including plastics
	Agriculture and food production		
	Environmental sciences, engineering, civil engineering	Environmental and civil engineering services	Same

Table B

Table 32 Clusters in Maine

Based on the definitions developed here, we can identify the following clusters (Table 32). The assignments between cluster types are subjective, and open to debate, which we encourage as continued examination of all these activities will greatly help shape appropriate actions in both the public and private sectors. We primarily distinguish between potential and emerging clusters by the level of ongoing commercial activity in Maine at present; and we primarily distinguish between emerging and sustainable clusters by the amount of time each has been operating.

Table 32 links the clusters we have found in our analysis with the current and future products that are associated with the basic knowledge and skills. Not all of the clusters have "potential economic activity" associated with them, or the diversity of current and future products is too great to discern specific opportunities. It is very important to recognize that the clusters with which we have associated "potential" economic activity are only those to which current knowledge extends. Developments in these clusters a decade or more from now likely depend on knowledge and skills yet to be created and products barely or not at all currently envisioned.

Identifying the clusters is a beginning, but not all clusters are equally composed. We would expect that potential and emerging clusters would be weaker than sustainable clusters, but even sustainable clusters may have weaknesses. These characteristics are explored in Table 33. Each of the four elements which are considered essential to cluster success is examined for each of the proposed clusters, based on the information contained in Chapters 5-11.

The three characteristics (in addition to the knowledge-skills base that defines clusters) can be briefly summarized as:

- Networks/Knowledge Spillovers: the extent of ties between the research organizations and commercial organizations leading from research to marketed products, plus the extent of networks if buyers/sellers and/or trade associations among firms.

- Entrepreneurship: the actions to turn research and new knowledge into new products, new services, or improvements in existing products and services that increase competitiveness. Entrepreneurship is not limited to starting new business; it is also a critical function in larger organizations.

- Production/Distribution: making and selling products

A score on a scale of 1-5 is indicated for each characteristic. These are judgments about the strength or weakness of a cluster. A score of 1 or 2 represents a weakness, a score of 4 or 5 a strength, and a score of 3 a mid-point representing no clear cut strengths or weaknesses. The cells in the table are color coded. The cross hatched cells indicate that there is a mixture of strengths and weaknesses within the cluster. For example, in Agriculture & Food Production, there is very strong entrepreneurship among the specialty food producers, but less so among commodity producers. In Chemistry and Chemical Engineering, there is a very strong relationship with the existing pulp & paper industry, but only an emerging set of cluster characteristics within bio-fuels and other bio-products.

Table 33 points out where each cluster fits on the "essential characteristics" model in very broad terms. However, it should not be interpreted to mean that even where there is strength that current conditions are satisfactory enough to assure a successful future. Nor should the term "sustainable" cluster be interpreted to mean that what exists now will in fact be sustained.

	Knowledge/Skills	Networks/ Knowledge Spillovers	Entrepreneurship	Production/ Distribution
Potential Clusters	Biomedical research	5	2	1
	Bioinformatics	1	1	1
	Measuring and controlling devices	2	4	4
	"New Media"	3	4	2
	Creating "green products"	1	3	2
Emerging Clusters	Genetics/genomics	4	2	1
	Antibodies and diagnostic materials/processes	4	4	5
	Geospatial analysis/GIS	4	4	4
Sustainable Clusters	Developing new materials by combination of dissimilar materials or finding new applications for existing materials	5	5	5
	Chemistry and chemical engineering	5	5	5
	Marine biology/oceanography/ husbandry related to aquaculture	5	5	5
	Forest harvesting and management	5	3	5
	Design, shaping, coating and composing materials of wood	5	2	5
	Design, shaping, coating and composing materials of metal, silicon, plastics, etc.	2	3	5
	Crop and soil sciences	5	4	5
	Agriculture and food production	5	4	5
	Environmental sciences, engineering, civil engineering	4	4	5
Key	Weakness	4 - 5 Strong Element		
	Moderate Strength	3 Middle Point		
	Strength	1 - 2 Weak Element		
	Mixed Strength and Weakness			

Table C

Table 33 Clusters and Major Cluster Characteristics

This analysis of clusters means there is a complex relationship between the sectors and clusters.

Figure 34 maps the clusters against the sectors. It shows the different stages of clusters and also shows several clusters which overlap one or more sectors. Most of these overlapping clusters are potential clusters, which represent potentially important areas of opportunity.

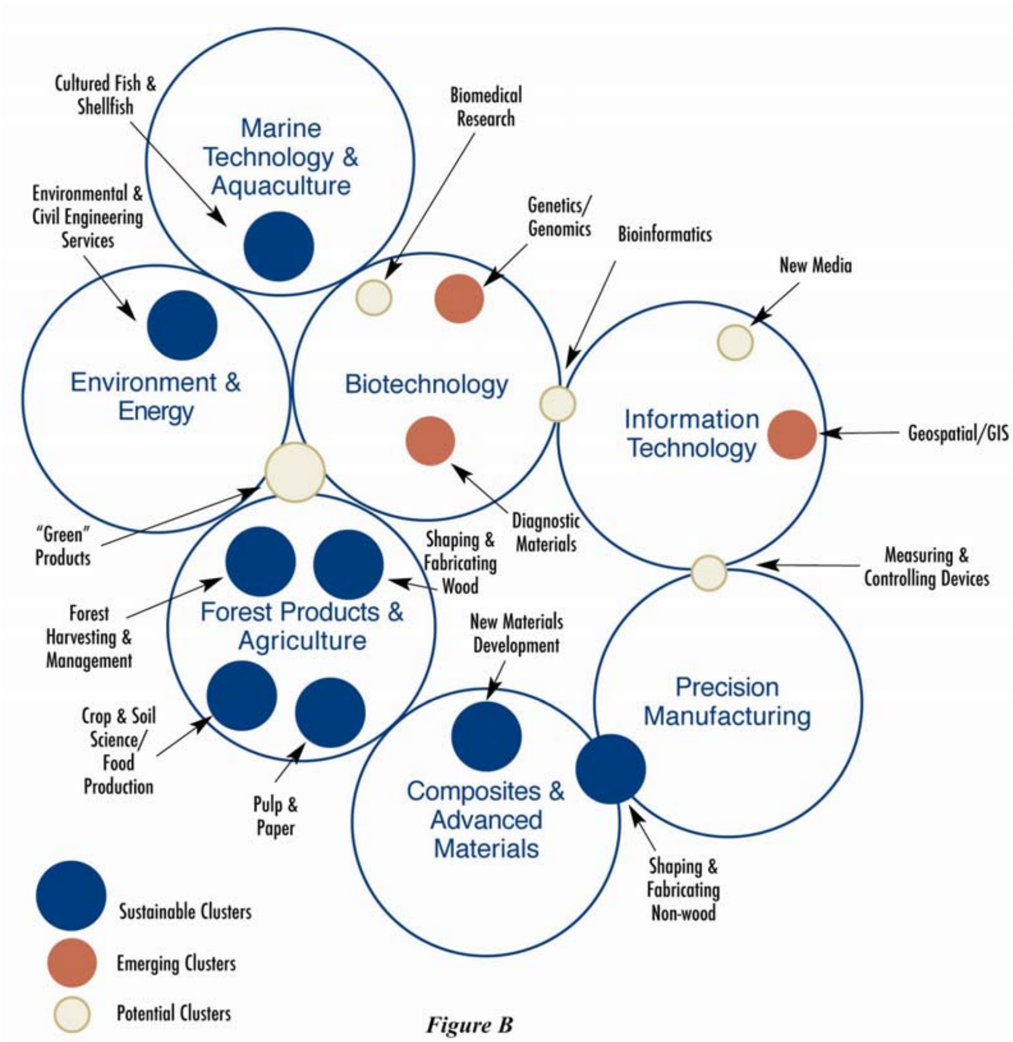


Figure 34 Cluster-Sector Mapping

Another overlapping cluster is "shaping and fabricating" which represents a set of knowledge and skills that is at the core of Precision Manufacturing, but is also critical to the commercial development of Composites and Advanced Materials as well as the wood products industry (though for simplicity, this link is not shown).

12.2 Clusters and Development Potential

Table 32 also links the underlying knowledge and skills basis of clusters with both current and possible future economic activity associated with each cluster. This is based on the analysis in each sector of both current and future economic activity that could result from enhanced and expanded knowledge and skills. A key finding of the 2002 CBER cluster study was that a mismatch existed between cluster strength and market development potential. Those sectors which exhibited the strongest characteristics of clusters were also ones where competition was intense and economic growth was very slow. Those sectors which appeared to have strong growth potential were also the ones in Maine which had the weakest cluster characteristics. The assessment from the 2002 report is shown in Table 33.

		Cluster Strength	
		Low	High
Growth Potential	Low	*Environmental* *Precision Manufacturing*	*Forest Products and Agriculture* *Aquaculture*
	High	*Biotechnology* *Info Technology* *Advanced Materials*	

Table 33 Cluster Strength and Market Potential: 2002

This picture has altered in important ways. First, we no longer speak of the sectors as, in the aggregate, being defined by cluster strengths or weaknesses. Rather we have to look at the clusters as defined here. Second, the economic potential for products from the clusters has changed. The analysis of market potential discussed in each of the sector chapters shows a much more complex picture. A quick review of that analysis for each sector identifies some of the important changes:

The top left quadrant we named "seeking direction" for a lack of clarity about the cluster characteristics and the weak market potential we saw at that time. With respect to **Precision manufacturing**, there are unquestionably severe weaknesses in economic performance driven by both the "tech bust" in electronics and continued competitive pressures on all manufactures. At the same time, the sector is hardly dormant. Fairchild Semiconductor was the single largest recipient of patents in Maine, and firms in precision manufacturing sector were also leaders in the MTI evaluation in new products developed Technological innovation is continuing in the sector. We identified no major potential growth markets, but the possibility of strengthening an already innovative measuring-and-controlling products industry by linking it to information technology development presents some interesting opportunities for both precision manufacturing and information technology.

Our analysis of the environmental products, now the **Environmental and Energy** sector, also shows some important changes. Potential and emerging clusters can be identified in this sector including green products and renewable energy, and there is good evidence of a sustainable cluster in environmental engineering and services. Evidence of strong cluster characteristics has also strengthened. Interviews indicate a still-young but solidifying set of networks and the analysis of research strengths and workforce points more clearly to a reasonably well-defined knowledge skills base in this sector. Market potential, particularly in the "green products" and in renewable energy, appears to be much higher than was the case when the earlier study was done and there is evidence of solid performance by the environmental engineering and services industries. Although this sector is still diffuse, it is also becoming more clearly defined.

Forest Products and Agriculture are seen as serving primarily mature slow growth markets despite their strength as clusters. This remains the case for what may be termed the commodity outputs of each subsector. However, improved export performance for forest products combined with the potential for a whole new array of products made from wood such as fuels and plastics opens up new growth possibilities in this subsector that were not present earlier. In agriculture and food production there has clearly been a major spurt in the growth of specialty food production, which has both created entirely new companies and helped sustain existing farming operations. These products, along with the development of engineered wood products like oriented strand lumber, are opening the doors in niche markets that could sustain economic activity at moderate to high levels.

In terms of markets and market potential, **Aquaculture** is perhaps the least changed. Worldwide and U.S. demand for seafood remains strong, and aquaculture is playing an important part in substituting for wild fisheries in providing seafood. But aquaculture, particularly salmon aquaculture, now faces new challenges in the market place from concerns (both real and imagined) about the environmental impacts of aquaculture products. The result is that growth potentials may be less than they were once thought to be, but remain solid. **Marine Technology** suffered a blow with the demise of major R&D activities at Bath Iron Works, but marine research remains vibrant and technologies applying to marine research represent a potential opportunity.

Among the sectors we identified as potential stars, those in the lower left hand corner of Table 33, we have also found important changes. **Composites and Advanced Materials**, the sector which taken as a whole most strongly exhibits cluster characteristics, has shown increased evidence of cluster strengths through the analysis of research strengths, the networks that have formed around the University of Maine's Advanced Engineered Wood Composites Development Center, and the relatively high specialization of the Maine economy in this sector. Economic performance has not been particularly strong, but there are a number of markets such as construction materials and renewable energy equipment that may spur growth in this sector.

Information technology presents a somewhat disappointing picture. Ironically this is partly due to the very successes in this sector. With IT products such as computers and cell phones now almost everywhere, the sector has entered a much more mature market phase in Maine and indeed worldwide. Thus, even after the "tech bust" of the early part of this decade, there is little prospect of another "tech boom" of the kind that occurred in the late 1990's. Maine does have some definite growth among IT occupations as the technology has diffused, but the development of new products has not coalesced around a sufficiently clear focus, with the exceptions of geospatial analysis and perhaps "new media." Other potential growth areas like bioinformatics are still small in Maine.

Biotechnology presents perhaps the most complex picture in terms of cluster strength/market potential. On the one hand, biomedical research facilities have clearly established themselves as important players in their fields, and investments in new research institutions and facilities is already underway. The biomedical research community has also developed an impressive set of networks, particularly in the establishment of the Graduate School of Biomedical Sciences. However, connections between the biomedical research organizations and commercialized products are just beginning. At the same time, the diagnostics/antibodies cluster appears to have achieved significant commercial success and is well embedded in Maine. It has a strong knowledge/skills base here and is very diverse in the products and markets it serves. But most firms remain small, serving highly specialized markets. In summation, we believe cluster strength is more evident in biotechnology in Maine today, but the market potential for large economic impacts remains some distance in the future.

This more refined view of market potentials suggests that there are really more opportunities for Maine's clusters and innovation capabilities to seize than is commonly realized. The question is whether they will be seized. The answer to this question depends greatly on what actions are taken.

12.3 Action Recommendations

What follows are recommendations that directly address the process of cluster development as developed in the analysis of this study. The recommended actions must be seen in the context of other actions by state and local governments in Maine to promote economic development. Many of our interviewees noted concerns about the cost of doing business in Maine. Of particular concern to a large number of interviewees in biotechnology, information technology, and environmental services is the issue of the adequacy of air travel connections, particularly through Portland. Maine's air travel connects are as essential to the functioning of these clusters as good telecommunications. We leave to other discussions the enumeration of actions to address these concerns and concentrate here on those specific things that relate to cluster development and that are not covered in broader debates about economic development policy.

Two features of clusters make devising public support programs for them particularly difficult: First, clusters are largely self organizing through a process that encompasses many small events; second, real commercial success, while dependent on the capabilities and capacities found in a region, will most likely come through innovations that cannot be foreseen with any clarity. (Feldman and Francis 2007). These argue for a set of policies that focus on building capacity in research and institutional networks, expanding communications among people and organizations, and developing capabilities to see both new problems and new solutions that can move from potential technologies to potential clusters to emerging clusters to sustainable clusters that are commercially successful. There are four broad areas where action is required:

- Feed the Pipeline
- Catalyze the Emergence and Growth of Clusters
- Put a Priority on People
- Fund Innovation

We also recommend that monitoring and evaluation of the cluster development process be continued.

<u>Feed the Pipeline: Continued Support for R&D</u>

We cannot overemphasize the importance of continued and enhanced support for research that is not immediately connected to commercialization of products or even of specific cluster development. Despite our best efforts, the future of scientific knowledge and of its commercial and economic development implications can only be dimly perceived. A decade or two hence it is very likely that a substantial proportion of Maine's technologically advanced economy will be based on knowledge, skills, and products which do not yet exist. Having made the commitment to supporting an economy increasingly based on technological innovation, Maine cannot stop "feeding the pipeline" in any of the areas in which research capacity already exists, nor adding to that capacity whenever possible. We recognize that this creates a real dilemma for state policy makers who must decide how much of the very scarce resources available will go to cluster development and how much to R&D which is not (yet) connected to clusters, but there is no escape from this dilemma if long term success is to be achieved. Of course, Maine need not make the investments alone, as the bulk of funding at least in some areas will come from the federal government or the private sector. Maine must judiciously catalyze investments by others and step in to seize promising opportunities that others do not yet support.

<u>Catalyze Clusters</u>

Broadly speaking, we identify six broad strategies that are applicable across all technology sectors for cluster enhancement. We believe these five broad areas should become strategic directions for the Maine Technology Institute Cluster Enhancement Award Program, and should guide the way in which other state programs influence cluster development. We recommend that MTI set aside a portion of annual cluster enhancement funds and invite proposals to address six areas:

- Develop services
- Build technology networks
- Decrease distance
- Make connections outside of Maine
- Plan infrastructure development
- Address cluster weaknesses

While each of these strategies may be broadly used for all clusters, where appropriate we note the specific clusters that could most benefit from a particular strategy.

<u>Developing Services for Technology Innovation</u>

Networks of organizations in clusters are usually depicted in terms of research organizations such as universities, commercial firms, and the firms that take research and turn it into commercial products. But there are additional organizations that are important to establishing successful clusters: service organizations. The importance of these organizations is illustrated in the discussion on **Biotechnology** in Chapter 5. An array of service organizations has emerged to become essential to the development of therapeutic products for human health by the complex networks among biotech firms, established pharmaceutical companies, and research organizations.

Maine has already begun to fund this type of support in the Maine Patent Program, which provides essential intellectual property assistance to firms and research organizations. Expertise in intellectual property, the complex finance of alliances and other inter-firm relationships for product development, the regulatory processes in the U.S., Europe and elsewhere, and the testing of products are all needed for biotechnology product development. Few of these services are supplied within Maine, limiting the size and reach of biotechnology sectors.

An example of a service oriented cluster enhancement program can be found in the **Environmental and Energy Technology clusters**. As noted in Chapter 7, one of the major development opportunities for environmental products lies in the increasing need for "green certified" products in the market place. The market for "green products" is large and growing, but the definition of "green products" is subject to numerous different standards defined by retailers, standard setting organizations (such as the U.S. Green Building Council), and governments. Developing expertise in the various definitions of "green" that could be used by manufacturers throughout Maine would lower the barriers to serving these markets and greatly expand Maine's reputation for green products.

A related effort that could be applied broadly across all sectors is to develop and share expertise on the various International Standards Organization (ISO) standards that set standards for product quality, safety, and environmental impact. ISO certification is routine at larger organizations competing in world markets, and growing technology firms in Maine should all have a plan to address the standards appropriate to their field.

Another example of services that are needed to encourage development of clusters comes from the analysis of **Metal Products Fabrication**. Technological innovation continues to be important in that sector, but the ferocious competition for manufacturing jobs means that Maine cannot rely only the quality and cost of our products but must emphasize value-added services to accompany the products. High quality logistics (e.g., just-in-time delivery), installation, and customer service need to be part of the competitive advantage of Maine manufacturing. The newly formed Maine Manufacturers Association (formerly the Maine Metal Products Association) has formed a business-services division to assist member companies in developing the business skills needed to take full advantage of the purely technical knowledge that is at the base of their operations.

A final example is the need for high quality information services to support R&D. It has been suggested that Maine should develop a world-class library of **biomedical research** to serve as a key foundation for knowledge generation in biotechnology. Such libraries are no longer buildings with rows of books, but highly organized online databases that bring together diverse sources from around the world. Such high quality information services could become a source of clusters by linking information technologies with the research done in other areas.

Providing Support for the Formation of Technology Networks

Technology networks composed of industry, academia, and resource providers can be used to develop and transfer resources and capabilities between cluster institutions. The focus of such networks would vary by cluster but networks expand participants' knowledge base, provide access to resources not available in their home institutions, and increase opportunities for collaborative efforts. Activities undertaken by such networks elsewhere include developing and maintaining an inventory of network capabilities, conducting topical workshops or seminars sponsored by the partners, creating web sites to facilitate sharing of information, and developing joint research opportunities and contributions to new intellectual property and capabilities.

Tech networks and trade associations are similar to one another in some important ways and different in others. Trade associations are often the nucleus around which networks are built. They play a particularly important role in the early stages of cluster formation, as they provide an identity, resources devoted to communications and organization, and opportunities for informal contact among interested organizations and individuals which are so critical to communications. Trade associations often also play important roles as the voice of an industry or other group in dealing with government; though this particular aspect of network development can sometimes become the central focus of the association's activities to the detriment of other roles the association might play (it is often easier to get people involved in an association when "threats" of government action are perceived).

Supporting trade associations, and particularly supporting activities that encourage "knowledge spillovers" within Maine or activities that will address some of the other cluster development strategies identified in this report, remains an important cluster development strategy. However, though trade associations may be the nucleus of the network, they are still only one node. Cluster enhancement has to develop other elements of networks.

Examples of technology networks can be found in western Massachusetts, where the Regional Technology Council has sponsored networks of regular connections among private firms and higher education institutions. One network focuses on materials and manufacturing and regularly links firms and regional higher education institutions to deal with issues around workforce development and creating opportunities for partnering and creating joint ventures. In Oregon, Portland State University began offering executive education seminars. This led to the creation of the Food Industry Leadership Center (FILC), a university-affiliated resource designed by and tailored to the food, beverage and consumer packaged goods industry. The Center, which promotes education, leadership and research, is funded entirely by industry.

Another example of fostering network development could be the creation of The Maine Research Conference Series. The knowledge spillovers that characterize clusters only occur with good communication within the networks of institutions. One of the most common and most effective means of communication within technical communities is the regular convening of research conferences. These are opportunities to bring together researchers to share their findings and insights, to identify new targets for research, and to undertake the informal networking among professionals so essential to the knowledge spillover process.

We recommend that MTI use cluster enhancement funds to sponsor regular research conferences in collaboration with trade associations, appropriate higher education programs, and other interested organizations such as government agencies. These should be distinguished from other forums by focusing on research and its applications; that is they should be modeled after standard scientific conferences with peer reviewed papers, organized panels on research topics, etc. The focus should be on research in Maine, but the conferences should be open to global audiences. They should be regularly held so that they become a routine connection point. Proceedings and other forms of building the research record should be used.

Existing examples of this kind of forum include the summer workshops regularly sponsored by the Mt. Desert Island Biological Laboratory and The Jackson Laboratory. **Biomedical Research** is a natural field for such conferences, but so are **geospatial information technologies, Environmental Engineering, and Composites.**

A final step that MTI could take in helping technology networks form or grow is to recognize that the products of its cluster enhancement award program are themselves a key resource for knowledge generation and spillovers. Cluster enhancement award recipients will often produce valuable knowledge that others can use, and so should be asked, whenever it makes sense, to make sure that any final reporting on the project includes a summary which not only discusses the project undertaken but explores the implications for others undertaking similar activities. MTI should make cluster enhancement reports widely available, and, when appropriate, should sponsor events at which people can learn about the latest MTI cluster research and develop ways to apply lessons learned from such research as broadly as possible.

Decrease Distance: Expand Use of Distance Diminishing Technologies

Despite the best efforts of people and institutions to connect with one another, and despite the transformative power of the Internet to decrease distance, Maine is still a very big place. Distances are long and winter is harsh. New generations of technology, under the heading of "virtual presence" will transform what has been known as "video conferencing" into something that is much more useful. Virtual presence is already an area of significant technological and sociological/psychological research. Deployment of virtual presence technologies, particularly with respect to activities where a very high degree of regular interaction will be required such as the functioning of the Graduate School of **Biomedical Sciences**, could be a major boost for some emerging and potential clusters, and might over time with sufficient scale become a possible area of research and commercialization within Maine.

High end video links, like virtual presence, will be key in some areas, but lower cost approaches are available. In 2006, National Semiconductor equipped every one of its 8,500 employees worldwide with a 30gb iPod as a means to deliver expanded and enhanced training. This is another example of how information technologies are transforming the education process. Creative use of information technologies for training and related activities could provide a significant stimulus to the potential **New Media** cluster while simultaneously enhancing the workforce in other clusters.

Make Connections Outside of Maine to Strengthen What Happens in Maine

While clusters are founded on the strength of the connections within regions, sometimes the ability to evolve from weaker to stronger clusters depends on connections outside the region. An example lies in **Biotechnology**, where the future development of clusters in that sector will likely depend on connections outside of Maine. But this point is not limited to biotech. The MTI evaluation data indicate that trade associations and other firms outside of Maine are key resources for many MTI clients across all sectors (Maine Center for Business and Economic Research 2007). At the same time, as noted in Chapter 3, over 70% of patents for inventions developed in Maine are assigned to companies headquartered outside of Maine.

Cluster enhancement grant applicants should be encouraged to develop connections and networks with organizations outside of Maine where these connections can be shown to be essential to developing stronger knowledge/skills, markets, etc. within Maine. In particular, connections to clusters elsewhere in New England that may strengthen a "New England" cluster of which Maine is part should be encouraged.

Infrastructure: Long Term Capital Planning

Maine has made significant investments over the past decade in the capital infrastructure of the research and development enterprise, and will likely continue to do so in the future. However, multi-million dollar investments designed to last several decades have often been made on the basis of a boom-bust cycle of political support that can all too easily result in decisions based on only the slimmest of pretexts to meet the current crisis yet greatly affecting the future. Given Maine's truly large lag in R&D, this has probably not been much of a problem in the last decade; everything that was built was desperately needed. But as Maine turns the corner to an era of adding capacity to what is already there, a short-term oriented sporadic decision process will ill serve Maine's competitive position.

For this reason, consideration should be given to developing a ten year capital investment plan for research and development capital facilities that might be funded with state bond funds or appropriations. Such capital plans, updated every five years, could include the needs of the University of Maine System, the Community College System, Maine Maritime Academy, the major biomedical research centers, the advanced technology development centers, and other institutions. Each institution should be responsible for compiling its own needs, and the creation of a consolidated plan might be undertaken by the Maine Innovation Advisory Board.

We recognize that capital planning will never, by itself, overcome the short term pressures of changing economic and political circumstances. If no battle plan survives contact with the enemy, no capital plan survives contact with the legislature. But a capital plan does force all parties to articulate and debate a long-range sense of possibilities, opportunities, needs, and strategies. A long-term capital plan for R&D investments may be more about the planning than the plan but it will be an important element in sustaining a vision of Maine's long-term commitment to a technologically innovative economy.

<u>Address Weaknesses</u>

Another view of possible actions is to examine Table 33 for the areas we have identified as weaknesses in the elements that make up the clusters and to address those deficiencies. Table 35 recapitulates the identified weaknesses from the analysis above. Addressing each weakness will require a different strategy for each cluster.

	Weakness
Biomedical research	Entrepreneurship
	Production
Bioinformatics	Entrepreneurship
	Production
Measuring and Controlling Devices	Networks/Knowledge Spillovers
"New Media"	Production/Distribution
Creating "green products"	Production/Distribution
Genetics/Genomics	Entrepreneurship
	Production/Distribution
Designing/Fabricating Wood Products	Entrepreneurship
Designing/Fabricating Metal/Electronics	Networks/Knowledge Spillovers
Chemistry/Chemical Engineering-Bio-products	R&D
Agriculture	Entrepreneurship

Table 35 Cluster Weaknesses

Biomedical Research, **Genetics and Genomics**, and **Bioinformatics** are all areas where the basic research work is ongoing in Maine at increasing levels of activity and sophistication. Translating that research into commercial products has not yet begun on a large scale, though this is really not surprising given the relative youth of much of Maine's major expansion into biotechnology and biomedical research. MTI grant programs exist to assist specific commercialization related activities once specific ideas are ready to attempt translation from lab to street. Each of the major research institutions is developing their internal capacity to assist researchers by making this transition when appropriate; supporting the development of this capacity, perhaps by expanding the "biotech services" function, may help speed the development of commercial ventures and products. In addition, MTI should seek to catalyze connections between biomedical and information technology organizations. If the potential cluster of bioinformatics is to emerge as a cluster, it would be best if it could do so in collaboration with Maine IT capabilities.

"Connections" is also the theme for **Measuring and Controlling Technologies** and for **Design and Fabrication of Metals and Electronics**. In the former case, measuring and controlling technologies is, like most of the electronics industry in Maine, a group of activities that is fairly isolated from the other parts of the Maine economy. There are many potential connections to information technology (merging hardware and software) and to specific applications related to other clusters, particularly in the environmental management and alternate energy development fields, where accurate real time monitoring of environmental conditions can be critical.

For **"New Media,"** we noted a weakness in the overall size of the commercial activities in the potential cluster. There are a number of small firms scattered in a few locations like the Bangor area, the Penobscot Bay region, and Portland that are the nucleus of a possible cluster but the volume of activity in this area needs to increase. New product development support through MTI is one strategy; but other strategies would be to support growth in demand by organizing opportunities for "New Media" producers to identify customer needs in fields like health care and education, and seek to develop new products in places that would be unlikely to look to New Media products for solutions. This is also a potential cluster where expanding markets outside Maine in major media centers like New York would be an important spur to cluster development.

The potential for a "**Green Products**" cluster hinges largely on the development of the kind of supportive services discussed above with respect to organizing and to communicating information about the evolving environmental standards around the world. Finding and sharing ways to meet environmental standards might also be the subject of the research conferences noted above.

We note a weakness in entrepreneurship in the **Agriculture** related clusters, but also note that this is mostly an issue in the commodity subsectors. MTI should investigate linking with the Maine Department of Agriculture's Farms for the Future program to provide additional funding to the planning or implementation grants directed at helping farmers diversify their incomes or improve their productivity. A coordinated approach to assistance for strategic planning, marketing assessment, and, where appropriate, technology research could be very useful. Though no analog program to Farms for the Future currently exists for small **Wood Products** producers currently, MTI and the Department of Conservation might investigate whether such a program might be worthwhile. This could be done after evaluating the experience of coordinated programs for agriculture.

Finally, we note that the **Chemistry/Chemical Engineering** cluster has a great deal of work to do in the field of bio-products/bio-fuels development. Here we can only note the need for continued support for R&D in this field, particularly after the NSF funding which has supported the initial stages of bio-products development ends.

A Priority on People

A knowledge/skills perspective on clusters requires a much more direct focus on education and Maine's ability to provide the technically competent workforce that will be needed. Much attention has been directed at research into product development, and appropriately so. Equal attention needs to be given to the development of the people who will generate the science and the products. Our research has identified three major workforce issues that could significantly limit the effectiveness of clusters:

5. The output of technically trained people in Maine is adequate at the associate's and bachelor's degree levels, but inadequate at the graduate level.

6. In consequence, firms in almost every technical field must recruit most of their specialized work force from out of state.

7. A number of clusters are facing severe work force shortages caused by an aging workforce and a lack of younger people willing to move in production type occupations.

1. Generating from Within Education Strategies

This will require the state, together with the institutions of higher education (both public and private), to undertake a thorough review of current institutions and programs with a view towards:

- Building firm foundations in the K-12 system. In this regard, the deans of the appropriate schools within higher education (including both the technology/science schools and the schools of education) should join with school superintendents and the Maine Mathematics and Science Alliance to create an ongoing forum on the technologically innovative economy to identify ways to improve both the curriculum of the K-12 system and to increase the number of students committed to study in these areas, particularly technology and engineering which are largely unaddressed at the K-12 levels.

- Consider reinvigorating the Maine Economic Improvement Fund in addition to increasing overall support for higher education in Maine.

- Within higher education, increase support for graduate education in the STEM fields, including both direct support to students and for expanded faculty resources both as researcher/teachers and to meet the needs of expanded and enhanced STEM education at the K-12 levels. Particular emphasis should be placed on interdisciplinary fields; Maine already has significant strengths in these areas, particularly at the University of Maine. More importantly, the leading edge of science is increasingly found at the boundaries between disciplines, and this represents a real opportunity to build on an existing Maine strength. One possible way to accomplish this objective would be to use MTI or other funds to seed challenge grants that would attract funds from industry to support student scholarships, fellowships, paid internships, and other support to lower the financial barriers to students studying in critical fields. Combined industry and public partnerships for the funding of additional faculty, long used as a model in many fields, where teaching resources in new fields need to be augmented.

- Work to develop industry partnerships. An example of addressing the needs for a STEM workforce using industry partnerships is found in Oklahoma, where the Oklahoma Center for the Advancement of Science and Technology has had in place for many years now an R&D Faculty and Student Internship Program that supports student internships and places faculty that teach undergraduates at R&D institutions or conducting applied research under the sponsorship of a firm. Both students and faculty obtain experience doing R&D in a workplace environment and it exposes students to opportunities in Oklahoma research institutions. The program provides between $10,000 and $30,000 for 1-2 years with companies providing matching funds. The program has been successful in encouraging students to seek advanced STEM degrees and retaining graduates in state.

2. Enhance and Expand Two-Way Knowledge and Skills Development Between Industry and Educational Institutions

The supply of a technically competent workforce in support of technological innovation is primarily a function of education and training institutions, particularly in higher education. But the innovation that drives changes emerges from both the laboratory and the shop floor. Educational institutions and training programs usually have some form of industry advisory groups; while private firms offer internship or co-operative education opportunities. These arrangements should be reviewed by all parties to make sure that they effectively incorporated and spur innovation.

2. Attracting from Without: Affirm Maine is a Place Highly Skilled People Want to Be

Developing a workforce capable of carrying the key knowledge and skills into the future, transforming new insights into commercially viable products, and, most importantly, developing whole new areas of knowledge and skills will rest not only on graduates produced from within Maine. Indeed, it is highly unlikely that even with massive investments in education that we could ever supply all our needs for a technologically literate and innovative workforce. Maine is simply too small and its demographic forces too adverse for this to happen. Maine is going to have to rely on recruiting people from outside the state to be the drivers of change in many instances. The interviews conducted in all of the sectors for this study make this point clear, but the point was particularly stressed in **Biotechnology, Information Technology, Electronics, Environmental Services, and Renewable Energy**.

For this reason, an important part of cluster development is to be found in the work currently underway by the Governor's Quality of Place Council. The group, which issued a preliminary report in December 2007, grows out of the Brookings Institution's observations that Maine's quality of place is a key resource for the economy. This may be obvious for such activities as tourism. It may be less obvious, but no less important, for technology cluster development. The recommendations of the Quality of Place Council will almost certainly lie outside the normal bounds of MTI and other organizations concerned with Maine's technology economy. However, the evidence we have accumulated of the importance of quality of place and recruiting high skilled workers needs to be inserted into the forthcoming debates about quality of place to make sure that people understand how critical the issues are.

3. Retaining a Technically Skilled Production Workforce

This is one of the most difficult challenges facing many of Maine's technology sectors, including **Agriculture, Forest Products, and Metal Products.** It is particularly critical to address because the regional economic stimulus from innovation in clusters depends to a great extent on capturing the production of products developed within the region. Recent declines in employment in these sectors have discouraged young people from taking jobs just as the older workforce is beginning to make a transition towards retirement. Firms and trade associations are working on ideas ranging from apprenticeships to scholarships to events exposing high school and college students to the opportunities available to them. These have mixed success, but deserve support, particularly for K-12 and Community College institutions.

Funding Innovation

Maine has been working to expand the level of research and development and of commercial innovation for some time, with the Maine Technology Institute at the center of those efforts. MTI programs have a demonstrated record of success addressing needs in all seven of the technology sectors. In the first part of these recommendations we focused on specific ideas for the MTI cluster enhancement program. The question here is how might MTI adapt its proven programs of development awards and seed grants to better support cluster development?

<u>Add a Knowledge/Skills Perspective to MTI Grant Programs</u>

For existing programs such as the Seed and Development Award programs of the Maine Technology Institute, we recommend that the following criteria be added to assessments of potential awards:

- How does the grant build on existing strengths in knowledge and skills?
- How does the grant lead to the creation of new knowledge and skills which will broaden the foundations for economic activity in Maine or in specific clusters?
- How does the grant support the transition from industry to potential cluster, from potential cluster to emerging cluster, or to the creation of a sustainable cluster?
- How does the grant support institutional collaboration among the various entities involved in creating, developing, applying, and commercializing the knowledge and skills central to the cluster?

The emphasis in these programs should not replace or dilute the creation of commercially successful products. We seek to connect activities under these programs more explicitly to the fundamental knowledge and skills on which all else depends when appropriate. We also recognize that our definitions of key knowledge/skills are preliminary and incomplete. The incorporation of these criteria within programs will allow MTI to build towards a more complete understanding the key knowledge and skills and also permit the evolution of knowledge and skills over time.

<u>Classify MTI Awards According to the Knowledge and Skills Base Rather than Targeted Product</u>

An implication of this perspective arises in the perennial problem of how to classify projects seeking support from MTI, or other state programs, when such projects clearly cross sectoral boundary. In these cases, we recommend: think "from," not "to." That is, upon what set of knowledge and skills does a project rest, not what products is it aimed at producing. For example, MariCal is a company whose R&D aims to apply developing knowledge in biochemistry to particular applications in marine animals. A "from" perspective would view MariCal's research as biotechnology rather than aquaculture. The Gulf of Maine Research Institute is seeking to expand its research capabilities in marine research in directions towards human health that are similar to what biotechnology firms do. We would argue that the research in this area, since it arises from Maine's strong capacities in understanding the ocean and its processes, should be considered part of marine science rather than biotechnology.

The "from not to" rule is likely to become increasingly important because we see many of the research activities currently underway as likely to be very round pegs in the sectoral square holes. Cellulosic ethanol, composite-built wind turbines, therapeutic drugs from the sea, from chemistry, and genetics are all current and on-the-horizon knowledge generation efforts any one of which could produce revolutionary new products. By applying the "from not to" rule, state R&D support can be firmly grounded in the basic approach to cluster building that we recommend: build on what we know how to do, and expand what we know how to do.

Monitoring and Evaluation

The approach we take to clusters in this report has implications for the monitoring and evaluation of Maine's R&D programs, including those of MTI. The best way to approach this will be to adapt the information about knowledge/skills that we recommend and incorporate it into both the grants management process and the evaluation process. Thus, the analysis of performance can be organized by the knowledge/skills defined here (and further defined through the grants process) in addition to the ways that they are currently organized.

12.3 Summary: Who Should Do What

Section 12.2 outlines an ambitious agenda of actions. Much of the work needs to be undertaken by the Maine Technology Institute and the Maine Department of Economic and Community Development which has overall responsibility for Maine's innovation strategies and programs. However, others need to play critical roles as well. Clusters are complex interactions requiring attention from a diversity of public and private agencies. MTI cannot do it alone. Herewith is a summary of recommended responsibility allocation in the series of action recommendations resulting from this analysis.

The Governor and Legislature:

Feed the pipeline. Maine's overall research and development capacity has grown enormously, but in most areas is still too small by national or world standards. Momentum gained over the past decade has to be maintained.

Refocus on People Maine has been very generous with meeting physical requirements for research. It must now become at least equally generous in assuring an adequate number of people who will make the real difference and assuring that Maine can attract highly skilled people, who could work almost anywhere, to enjoy not only our quality of life but also to achieve real professional success.

Maine's Educational Institutions

It is up to the educational institutions in Maine, including the K-12 system and all of the institutions of higher education, to develop strategies to make Maine a place where the workforce that emerges from the education system is itself a source of competitive advantage for all of Maine's current, and future, technology clusters. This means:

Renewed and expanded attention to STEM education at all levels, but particularly at the graduate level in the University of Maine System.

Expand and enhance Maine's existing strengths in interdisciplinary research, which is likely to be a source of significant competitive advantage because this type of research is generally seen as one of the most important developments in contemporary science.

Combine resources from the public, private, and philanthropic sectors to fund the needed programs.

Work with mature industries to increase the supply of trained and skilled younger workers

Prepare an educational plan equivalent to the state's Science and Technology Plan. This should be a joint product of all of the education institutions and submitted to the legislature and Governor for their action.

Maine Technology Institute / Department of Economic and Community Development

Catalyze Clusters through

- Developing services
- Building tech networks
- Decreasing distance
- Making connections outside of Maine
- Planning infrastructure development
- Addressing weaknesses in existing clusters
- Developing potential clusters into emerging clusters

Modify Current Support Programs to build Knowledge & Skills

- Add a knowledge/skills evaluation component into seed grant and development award decisions
- Classify MTI awards according to the knowledge and skills base being developed rather than the product

Continue Monitoring and Evaluation of Cluster Development

12. 4 Challenges Ahead

The picture that emerges from this analysis is, on the whole, a positive one. Real progress has been made in spurring innovation and in developing clusters, partly as a result of public support and partly as the result of the energy and commitment of numerous people. All of the sectors have made progress to one degree or another in innovation and in establishing within Maine the networks of relationships upon which clusters can be built. Some have shown solid economic growth, while others remain threatened by larger economic forces.

However, there are real challenges ahead. Maine is by no means the only state, or the only region in the industrialized world, seeking to find a new role in the global post-industrial twenty-first century. Every state in the U.S. has undertaken some form of R&D support; every state is looking to develop some form of technologically innovative clusters, and many are doing it with far more resources than Maine.

In the field of biotechnology alone, California is investing a $3 billion bond (approved by the voters in 2005) in stem cell research, and Massachusetts' Governor has proposed spending $1 billion over the next decade in the same field. California and Massachusetts already have a major portion of the biotechnology research, but other states are competing as well. North Carolina is investing $1.5 billion, $1 billion of which is coming from a single private donor, to create a biotechnology university in an old textile mill town. Florida is investing $200 million just to bring top biomedical scientists to Florida universities (Fischer 2007). Maine cannot hope to match these sums, but it cannot hope to achieve more by investing less and less in the key programs and institutions, including higher education, on which everything else depends.

Another challenge goes to the heart of what we were recommending in this report, and that is to identify important targets of opportunity for Maine's R&D and cluster investments. We believe the opportunities we have identified are real and should be pursued vigorously. But we are also acutely aware of the large volume of warnings about the dangers of "industrial policy" in which governments pick winners and designate losers. The primary danger is that resources will be concentrated in a few areas, some of which may indeed pay off, but at the cost of perhaps missing other opportunities that could have even larger successes. The unhappy experience of Utah with cold fusion is a case in point (Voss 1999).

Already there are major new areas of research that could be even more influential than today's dominant models of research that are under development, including systems biology and nanotechnology. Maine research institutions are at the earliest stages of investigating these new avenues of research. For example, the Gulf of Maine Research Institute has already worked with other researchers and institutions, in and outside Maine, to establish a Maine Biological Nanotechnology Effort Consortium.

The real progress that Maine is making in creating a more technologically innovative economy can thus obscure how big the task that we are undertaking really is, and how much effort is still going to be needed to succeed. What has been accomplished to date is only a prelude to what must be accomplished in the future.

Appendix 1 Criteria for Selecting Benchmark States

In order to judge the performance of Maine's industry clusters, we compared them to a set of benchmark states. For benchmarks to be useful, they must share at least some common features. In this case, we were looking for benchmarks that had concentrations of the industry clusters being examined but that also shared other characteristics with Maine in order to try to compare "apples" to "apples." The project team considered the following factors to identify potential benchmark states:

- Presence of industry sectors that are found in Maine
- Similarity in size as measured by total employment
- Similarity in economic structure as measured by manufacturing as a share of total employment
- Limited R&D base as indicated by EPSCoR status
- Presence of programs to support technology-based economic development.

These criteria resulted in identification of a universe of 8 possibilities, from which the following set of six was selected by the project team in consultation with the Maine Office of Innovation and the Maine Technology Institute: Connecticut, Idaho, Iowa, Oregon, Vermont and Wisconsin. These states were chosen for the following reasons:

- **Connecticut:** Connecticut is a good match with Maine in terms of the presence of similar industry clusters. It is located in New England and state government has a history of active programs to promote science and technology-based development, similar to Maine.
- **Idaho:** Among the states, Idaho is most comparable to Maine in terms of size and economic structure. Both states have a small population base (519,000 total employees in Idaho and 497,000 total employees in Maine) spread out over a large geographic region. Both states have a strong agricultural and food products sector, a significant aquaculture industry, established electronic sectors, and emerging bioscience sectors. Idaho is also an EPSCoR state. State government in Idaho has not as actively supported technology-based economic development as has the State of Maine.
- **Iowa:** Iowa is a somewhat larger state with almost 3 million workers but its economy is similar to Maine's. It has both an agricultural and manufacturing base. Iowa is largely rural with a dispersed population. Its largest industry clusters are processed food manufacturing and financial services. Its universities have played a strong role in technology-based economic development and state government is seeking to grow its IT, bioscience, and advanced manufacturing industry clusters.
- **Oregon:** Oregon is a good match for Maine in terms of its industry make-up with forestry, wood products, agriculture, aquaculture, and IT being important contributors to the Oregon economy. State policy has a focus on cluster development but state support to technology-based economic development has been limited.
- **Vermont:** Vermont was included less because its economy is similar to Maine but because it is a neighboring small state with a limited R&D base (Vermont is an EPSCoR state) that

appears to be succeeding in growing its IT sector. Vermont has a food processing and furniture industry.

- **Wisconsin.** Wisconsin is one of the top states in forest product shipments and an emerging bioscience sector. It has seen strong growth in the medical device cluster but its biotechnology sector is still emerging. The university has played a strong role in technology-based economic development but state support has been somewhat limited.

Two other states that were considered but not selected were North Carolina and Washington. Both states match well with Maine in terms of their industry clusters but it was felt that their much larger R&D base, established research infrastructure and presence of very large technology economies would limit their use as benchmarks.

Appendix 2 Employment Analysis: Overview and Data

For purposes of this analysis, we arrange the seven technology sectors into ten sectors. We separate Engineering and Other Scientific/Technical Services from Environmental Services. Much of the activity in Engineering and Other Technical Services is environmentally related, but not all. We separate the two to examine the more clearly defined environmental industries on their own. We separately analyze Computer & Electronics Manufacturing from other Information Technologies. The manufacturing industries, such as semiconductors, may be arguably included in either the information technology or in the precision manufacturing sectors. We separate them to permit Electronics Manufacturing's role to be considered in either sector. Finally, we do not have a category for "marine technology" since the classification system we use does not distinguish that type of activity.

Maine's technology sectors span a wide variety of economic activities from a large, specialized and mature lumber, paper, and wood products sector to an emerging biotechnology sector and to a small but specialized aquaculture industry. An overview of employment, establishments, and wages for these industry clusters in Maine and in the U.S. as a whole is presented in table A-1 (Note: Table A-1 is a composite of tables in the chapters on each sector).

Table A-1. Total private sector employment, establishment, and wage comparison, Maine vs. the U.S., 2001-2005

MAINE	Total Private Sector	Biotech	Composites & Advanced Materials	Engineering & Other Sci/Technical Services	Environmental Services & Alt. Energy	Crop, Food, & Beverage Production
Establishments						
2001	43,232	105	81	541	252	476
2005	45,189	124	90	622	264	482
2001-05 % change	4.5%	18.5%	10.6%	14.9%	4.8%	1.3%
Employment						
2001	496,432	3,162	1,447	3,173	1,877	7,303
2005	495,554	3,712	1,297	3,196	1,743	7,778
2001-05 % change	-0.2%	**17.4%**	-10.3%	**0.7%**	-7.1%	**6.5%**
Average Annual Wages						
2001	$ 28,397	$ 40,020	$ 28,744	$ 50,525	$ 38,078	$ 24,923
2005	$ 32,106	$ 46,727	$ 36,247	$ 55,834	$ 42,511	$ 28,209
2001-05 % change	13.1%	16.8%	26.1%	10.5%	11.6%	13.2%
Location Quotient						
2001	1.00	0.78	**1.76**	0.63	0.87	0.76
2005	1.00	0.91	**1.73**	0.59	0.81	0.84
UNITED STATES						
Establishments						
2001	7,733,520	24,670	2,850	77,650	35,273	108,696
2005	8,308,128	25,552	2,799	93,175	37,262	104,325
2001-05 % change	7.4%	3.6%	-1.8%	20.0%	5.6%	-4.0%
Employment						
2001	109,321,800	895,792	180,636	1,104,633	474,414	2,118,565
2005	110,634,500	913,427	167,651	1,202,891	480,458	2,058,080
2001-05 % change	**1.2%**	**2.0%**	-7.2%	**8.9%**	**1.3%**	-2.9%
Average Annual Wages						
2001	$ 36,159	$ 61,237	$ 49,021	$ 62,148	$ 47,682	$ 27,266
2005	$ 40,499	$ 73,980	$ 54,547	$ 72,302	$ 53,613	$ 30,418
2001-05 % change	12.0%	20.8%	11.3%	16.3%	12.4%	11.6%

Table 1. Total private sector and employment, establishment, and wage comparison, Maine vs. the U.S., 2001-2005 Continued…

MAINE	Lumber, Paper, & Wood Products	Information Technology	Computer & Electronics Mfg.	Fabricated Metals & Machinery Mfg.	Aquaculture Industry
Establishments					
2001	1,056	773	58	359	27
2005	975	882	66	337	18
2001-05 % change	-7.7%	14.1%	13.8%	-6.1%	-33.3%
Employment					
2001	24,452	5,316	5,767	8,167	288
2005	20,560	4,542	3,479	6,846	106
2001-05 % change	-15.9%	-14.6%	-39.7%	-16.2%	-63.2%
Average Annual Wages					
2001	$ 40,014	$ 41,808	$ 44,445	$ 37,261	$ 29,375
2005	$ 44,374	$ 51,333	$ 61,315	$ 41,988	$ 30,943
2001-05 % change	10.9%	22.8%	38.0%	12.7%	5.3%
Location Quotient					
2001	**2.86**	0.56	0.73	0.59	**9.93**
2005	**2.71**	0.55	0.59	0.57	**4.02**
UNITED STATES					
Establishments					
2001	67,765	187,939	22,374	99,581	758
2005	62,248	184,951	19,689	91,850	737
2001-05 % change	-8.1%	-1.6%	-12.0%	-7.8%	-2.8%
Employment					
2001	1,884,018	2,079,337	1,749,403	3,028,992	6,386
2005	1,693,872	1,845,622	1,308,039	2,673,565	5,886
2001-05 % change	-10.1%	-11.2%	-25.2%	-11.7%	-7.8%
Average Annual Wages					
2001	$ 34,392	$ 76,313	$ 64,667	$ 40,962	$ 23,652
2005	$ 38,625	$ 81,291	$ 77,112	$ 46,655	$ 27,427
2001-05 % change	12.3%	6.5%	19.2%	13.9%	16.0%

Source: Battelle analysis of BLS, QCEW data from IMPLAN.

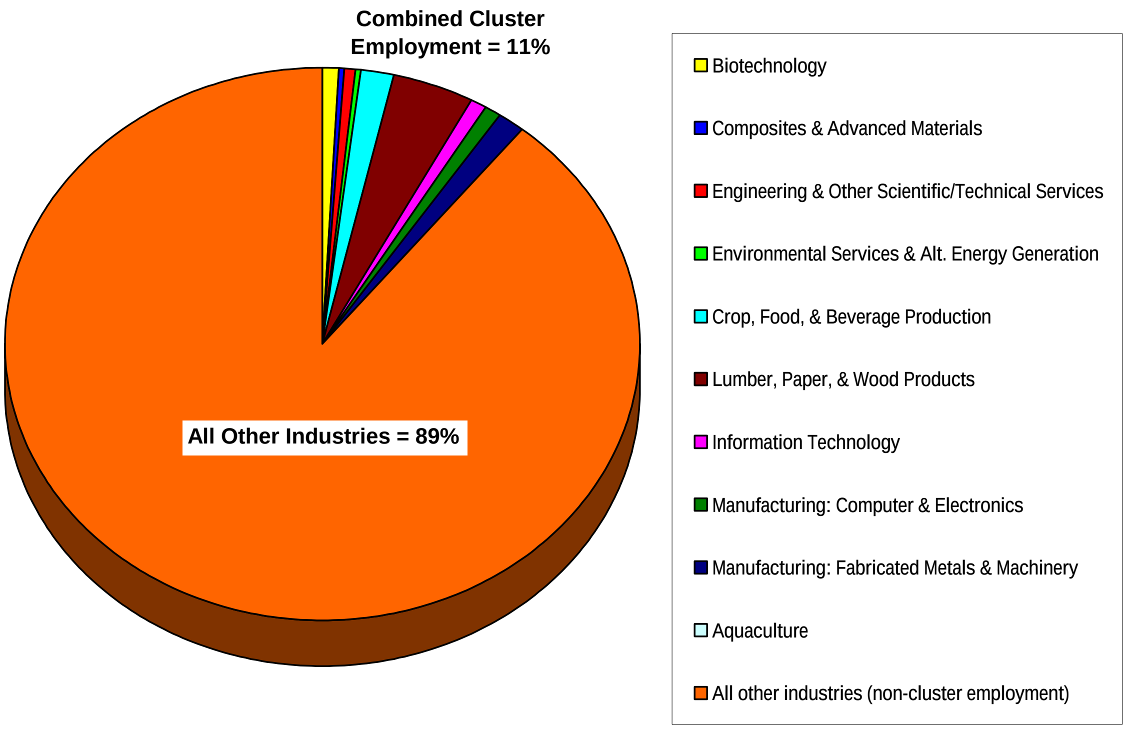
Note: Figures in Red denote specialized industry location quotients. Figures in Blue denote positive employment growth during the 2001 to 2005 period.

Maine's total private sector has regained its overall employment level since the business cycle peak in 2001 (down just 0.2 percent by 2005). This compares to overall national job growth of 1.2 percent during the 2001 to 2005 period. Average 2005 private sector wages in Maine remain below those for the nation: $32,106 for Maine versus $40,499 for the U.S.

Among Maine's ten major industry clusters, three have a specialized location quotient (LQ) in 2005: lumber, paper, and wood products (2.71); composites and advanced materials (1.73); and the aquaculture industry (4.02). Three other clusters experienced net job growth from 2001 to 2005: biotechnology (up 17 percent); crop, food, and beverage production (up 6.5 percent); and engineering and other technical services (up nearly 1 percent).

Figure 1 shows the employment composition of the Maine economy in 2005. The ten major clusters combine to account for about 11 percent of statewide employment. The lumber, paper, and wood products sector is the largest among the clusters, making up 4 percent of total state jobs.

Figure A-1. Employment composition in Maine technology sectors and non-technology sector jobs,



2005

The North American Industry Classification System (NAICS) is the official Federal government system for classifying establishments and their activities into the appropriate sectors. The NAICS is based on the production processes of firms and categorizing them in groups with other establishments engaged in the same or similar activities. NAICS industries at varying levels of detail were selected for this analysis and together make up the ten major clusters.[16] A full list of the Maine clusters and their corresponding NAICS codes is shown in Table A-2.

[16] Employment data organized by the NAICS system is available only since 2001. NAICS data is largely incompatible with data prior to 2001, which was organized on the no-longer-used Standard Industrial Classification (SIC) system.

Table A-2. Maine clusters and NAICS codes

NAICS Code	NAICS Description
Biotechnology	
3254	Pharmaceutical and Medicine Mfg.
3391	Medical Equipment and Supplies Mfg.
541710**	R&D in the Physical, Engineering, and Life Sciences
334510	Electro medical and Electrotherapeutic Apparatus Mfg.
334516	Analytical Laboratory Instrument Mfg.
334517	Irradiation Apparatus Mfg.
Composites & Advanced Materials	
3252	Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Mfg.
336612	Boat Building
Engineering & Other Scientific/Technical Services	
541710***	R&D in the Physical, Engineering, and Life Sciences
541330	Engineering Services
541690	Other Scientific and Technical Consulting Services
Environmental Services & Alternative Energy Generation	
2213	Water, Sewage and Other Systems
5622	Waste Treatment and Disposal
5629	Remediation and Other Waste Management Services
54138	Testing Laboratories
221119	Other Electric Power Generation
541620	Environmental Consulting Services
Forest Products & Agriculture: Crop, Food, & Beverage Production	
111	Crop Production
112	Animal Production
1151	Support Activities for Crop Production
1152	Support Activities for Animal Production
3113	Sugar and Confectionery Product Mfg.
3114	Fruit and Vegetable Preserving and Specialty Food Mfg.
3115	Dairy Product Mfg.
3118	Bakeries and Tortilla Mfg.
3119	Other Food Mfg.
3121	Beverage Mfg.
Forest Products & Agriculture: Lumber, Paper, & Wood Products	
113	Forestry and Logging
321	Wood Product Mfg.
322	Paper Mfg.
337	Furniture and Related Product Mfg.
1153	Support Activities for Forestry
Information Technology	
5415	Computer Systems Design and Related Services
511210	Software Publishers
516110	Internet Publishing and Broadcasting
518111	Internet Service Providers

NAICS Code	NAICS Description
518112	Web Search Portals
518210	Data Processing, Hosting, and Related Services
Manufacturing: Computer & Electronics	
334	Computer and Electronic Product Mfg.
Manufacturing: Fabricated Metals & Machinery	
332	Fabricated Metal Product Mfg.
333	Machinery Mfg.
Aquaculture	
1125	Animal Aquaculture

**Only the relevant life sciences share of R&D is included here.

***Only non-life sciences R&D is included here.

One of the 6-digit NAICS in the table above, physical, engineering, and biological research (NAICS 541710), was adjusted/split in this analysis to include only the share of this industry directly engaged in biological or other life sciences activities for the biotechnology cluster and the other portion included in the engineering services cluster. To isolate these relevant life science components, Battelle used information and data from the U.S. Census Bureau's Economic Census.

The following analysis examines data and corresponding trends in Maine, the U.S. as a whole, and six comparison or benchmark states (Connecticut, Idaho, Iowa, Oregon, Vermont, and Wisconsin) in these industry clusters from 2001 to 2005. For employment analysis, the Bureau of Labor Statistics' (BLS) Quarterly Census of Employment and Wages (QCEW) data are used. The QCEW data (formerly known as the ES-202 program) are the most current, detailed state- and county-level industry employment, establishment, and wage figures available. An "enhanced" version of these state and county data from a private vendor, the Minnesota IMPLAN Group, Inc., are used by Battelle for this analysis since this data series imputes estimates of data suppressed for confidentiality reasons.

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

The following analysis will focus on the current state of each of the ten major clusters of the Maine economy from an employment, establishment, and wage perspective.

Appendix 3 Standard Occupational Codes Used

	Computer and Mathematical Operations	
15-0000	All listed Except Exclude: 15-2011 (Actuaries) and 15-2031 (Operations Research Analysts)	
	Architecture and Engineering	
	17-2021	Agricultural Engineers
	17-2041	Biomedical Engineers
	17-2051	Chemical Engineers
	17-2061	Computer Hardware Engineers
	17-2071	Electrical Engineers
	17-2072	Electronics Engineers, Except Computer
	17-2081	Environmental Engineers
	17-2112	Industrial Engineers
17-0000	17-2121	Marine Engineers and Naval Architects
	17-2131	Materials Engineers
	17-2141	Mechanical Engineers
	17-3012	Electrical and Electronics Drafters
	17-3013	Mechanical Drafters
	17-3023	Electrical and Electronics Engineering Technicians
	17-3024	Electro-Mechanical Engineering Technicians
	17-3025	Environmental Engineering Technicians
	17-3031	Surveying and Mapping Technicians
	17-1021	Cartographers and Photogrammetrists
	Life, Physical and Social Science Occupations	
	19-1011	Animal Scientists
	19-1012	Food Scientists and Technologists
	19-1013	Soil and Plant Scientists
	19-1021	Biochemists and Biophysicists
	19-1022	Microbiologists
	19-1023	Zoologists and Wildlife Biologists
	19-1029	Other Biological Scientists
	19-1031	Conservation Scientists
	19-1032	Foresters
	19-1041	Epidemiologists
	19-1042	Other Medical Scientists
19-0000	19-2021	Physicists
	19-2031	Chemists
	19-2032	Materials Scientists
	19-2041	Environmental Scientists
	19-2042	Geoscientists
	19-2043	Hydrologists
	19-2099	Other Physical Scientists
	19-4011	Agricultural and Food Science Technicians
	19-4021	Biological Technicians
	19-4031	Chemical Technicians
	19-4041	Geological Technicians
	19-4091	Environmental Science and Protection Technicians
	19-4093	Forest Science Technicians
	19-4099	Other Life, Physical, Social Science Technicians

Appendix 4 List of Interviewees

All Sectors

Jake Ward	University of Maine	
Rita Heimes	Maine Patent Center	University of Maine School of Law

Biotechnology

Bill Harris	Biotechnology Association of Maine
Ken Ault	Maine Medical Center Research Institute
Todd Keillor	Independent Consultant
Peter Wells	The Jackson Laboratory
Janet Yancy-Wrona	Aiko Biotechnology
Don Perkins	Gulf of Maine Research Institute
Janet Hock	Maine Institute for Human Genetics and Health
Linda Diou	Meridian Bioscience
Barbara Knowles	The Jackson Laboratory

Environment & Energy

Clayton Kyle	CHK Capital
John Ferland	E2 Tech
Harley Lee	Endless Energy
Jim Keil	Stantec
Malcolm Poole	WH Shurtleff
Tom Austin	Maine Public Utilities Commission
Al Curran	Woodard & Curran

Composites and Advanced Materials

Paul Rich	Maine Built Boats	
Susan Swanton	Maine Marine Trades Association	
John Dorrer	Maine Department of Labor	
Martin Grimnes	Harbor Technologies	
Robert Lindyberg	Advanced Engineered Wood Composite Center	University of Maine
Mike McClain	Hodgdon Yachts	
Steve Von Vogt	Maine Marine Manufacturing	
Martin Grohman	Correct Building Products	
Steve Clark	Solon Manufacturing	

Information Technology

Ben Cameron	Abacus Technologies Creations
Zachariah Conover	CrossRate Technology, LLC
Erik Schwartz	Foneshow
Ashok Nalamalapu	ICST
Dana Hutchins	Image Works Multimedia
Stephen Hand	Know Technology, LLC
Chuck Farrel	Know Technology, LLC
Alan Hinsey	Knox/Waldo Regional Economic Development Council
Anne Yanner	Penobscot Bay Media
Peter Murray	Quantrix
Rory Eckardt	RE Consulting
Debbie Neuman	Target Technology Center
Joseph Kumiszcza	Technology Association of Maine
Charles Donnelly	The Jackson Laboratory
George Markowsky	Trefoil Corporation
Robert Sansone	Tyler Technologies
Owen Smith	University of Maine New Media Program
Mike Worboy	University of Maine, Department of Spatial Information Science and Engineering
Charles Welty	University of Southern Maine
Julie Ellis	University of Southern Maine
Nathan Hankla	versionZero
George Hogan	Wright Express

Marine Technology and Aquaculture

Dave Townsend	School of Marine Sciences	University of Maine
Phil Yund	Marine Science Center	University of New England
Sebastian Bell	Maine Aquaculture Association	
Michael Sieracki	Bigelow Laboratory for Ocean Sciences	
Chris Davis	Maine Aquaculture Innovation Center	
Stephen Page	Ocean Farm Technologies	
Ryan Curran	Winterpoint Oyster Farm	
David Hennessy	Winterpoint Oyster Farm	
Bill Harris	MariCal	

Forest Products & Agriculture

Alfred Bushway	University of Maine, Department of Food Science and Human Nutrition
John Rebar	University of Maine Cooperative Extension
Steve Shaler	University of Maine Forest Bioproducts Research Initiative
Bruce Bornstein	ILC Timberlands
Cal Hancock	Hancock Gourmet Lobster Company
Eric Kingsley	Innovative Natural Resources Solutions LLC
Rory Eckardt	RE Consulting
Eloise Vitelli	Centers for Women, Work, and Community

Precision Manufacturing

Lisa Martin	Maine Manufacturers Association
Jon McLaughlin	Southern Aroostook Development Corporation
Wick Johnson	Kennebec Tool & Die
Cheryl Bolduc	Southern Maine Industries
Ann Gauthier	National Semiconductor
Brenda Chandler	Fairchild Semiconductor
David Russell	Fairchild Semiconductor

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