THE NEW ENGLAND COUNCIL

Deloitte.

Advanced to Advantageous: The Case for New England's Manufacturing Revolution

The New England Council and
Deloitte Consulting LLP

April 2015

Introduction

Dear Council Members,

In 2009, The New England Council teamed with Deloitte Consulting LLP to produce a report that examined the advanced manufacturing industry in New England. The report explored the economics and emerging trends within the industry across each of the six New England states, as well as the region as a whole. The findings from that analysis provided strong evidence that dispelled the notion that advanced manufacturing is a dying industry in New England. To the contrary, the data revealed that advanced manufacturing had recovered quickly from the Great Recession, positioning the New England region for economic and employment growth, despite some longstanding policy and workforce challenges to address.

Today, the Council and Deloitte have teamed together once again to update this report. As in 2009, Deloitte has performed this work on a pro-bono basis, bringing forward their top advisors in manufacturing, government, and economic development strategy to lead the research and conduct interviews with a broad cross-section of New England stakeholders. The 2015 report includes refreshed data covering the past five years (Where We Are Now), the identification of emerging “game-changers” that are propelling advanced manufacturing forward (Where We Are Going), and a discussion of the persistent issues that impact industry growth, alongside actionable recommendations to address them (How We Get There). Our hope is that the Council members who view this information will become empowered as leaders to support the advanced manufacturing industry in affecting the kind of change that will move our region’s economy forward for all New Englanders.

Advanced manufacturing is an essential driver of New England’s economy, and the potential for further growth and diversification remains. However, the window of opportunity is closing – the industry faces several substantive challenges that we must collectively address in order to take advantage of investments that, without action, may not reach their potential or worse, may do so outside the New England region. By improving workforce development, addressing obstacles that add to the cost and complexity of doing business, and assembling a tightly integrated ecosystem of partners in industry, government and education to implement the recommendations contained in this report, New England, as a region, can harness the collective action necessary to sustain advanced manufacturing for generations to come.

The key takeaway from this report is a clear and urgent call to action for the New England business, education, and policymaking communities: diverse stakeholders must work together to overcome challenges and build the networked, collaborative environment needed for the advanced manufacturing industry in the region. I hope that as a leader in your profession, you will join The New England Council in taking up this mission to support the region’s prosperity.

Yours Sincerely,

James T. Brett
President and CEO
The New England Council

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Executive Overview

For some, the mere mention of the term "manufacturing" evokes connotations rooted in prior decades – Dirty, Dark, Dangerous, and Declining. However, the advent of advanced manufacturing in the United States has firmly relegated this outdated alliteration regarding America's backbone industry to the history books. Advanced manufacturing is not performed in a dingy setting, unskilled labor no longer provides the arms and legs for production, and value creation is no longer a pure low-cost input game: small-batching, highly precise components, customization and complex designs are pushing the need for more and better technology and a more highly skilled workforce.

In addition to the skills, innovation and technology elements described, advanced manufacturing relies on information, and this element makes the collaborative network that surrounds the industry of paramount importance. An advanced manufacturing industry is regionally advantaged by the depth and diversity of the collaborative network (or "cluster") that surrounds it. New England's cluster springs from a rich history dating back to its role as the birthplace of the Industrial Revolution in America; the heyday of the shipbuilding yards and textile mills may have waned, but the highly-skilled, advanced manufacturing networks that evolved from it are poised to have a dramatic impact on the economy in New England.

> One might suggest that the four "D's" of manufacturing be replaced by the four "A's" of advanced manufacturing: Advanced, Advantaged, Added-Value and Accelerating.

Emerging economics favor a knowledge-driven, networked economy, and as such, New England has carved out a favorable niche in several key sectors including: a) signal processing, navigation, optics and measurement, b) aerospace and defense, c) medical devices and biotechnology, d) semiconductors and complex electronics, and e) precision machining. Region-wide capabilities in software, artificial intelligence, robotics, and advanced materials further strengthen these core industry clusters, preparing New England to trailblaze the new technology frontier brought about by disruptive innovation and "game changer" technologies including digital design and prototyping, additive manufacturing/3D printing, and the "Internet of Things"

Despite the strength of the advanced manufacturing network in New England, the cluster is not without its challenges. In addition to the region's comparatively high cost of doing business, New England faces a shortage of qualified labor to sustain growth, and advanced manufacturing in particular suffers from a lack of brand awareness that keeps talent at arm's length from meaningful employment opportunities. Coupled with a generation of incumbent workers nearing retirement, the concerns over where to find and how to train the next generation of advanced manufacturing workers is reaching critical levels of need. Additionally, small and medium manufacturers (SMEs) struggle against market failures to scale effectively and innovate/adopt emerging technologies at the rate demanded by their larger colleagues throughout the supply chain, and a complex and ever-changing business regulatory environment diverts resources from their highest and best use (growth) to compliance activities. The cumulative effect of these challenges is to

restrain overall productivity and growth across the region, keeping it below levels both desirable and attainable. However, within each of these challenges lies a latent opportunity to be harnessed, and across the region, numerous dedicated organizations have taken up the gauntlet and fashioned responsive and innovative programs, “islands of excellence” that can and should be scaled across the New England states and the region as a whole.

Based on the findings in this report, one might suggest that the aforementioned four “D’s” of manufacturing mentioned should be replaced by the four “A’s” of advanced manufacturing – Advanced, Advantaged, Added-Value, and Accelerating. As demonstrated in the analysis that follows, the implications of this paradigm shift for the New England region are myriad.

Study Objectives

The New England Council (NEC) commissioned a joint study with Deloitte in 2014 to examine industry growth in advanced manufacturing across New England. The objective of that study (which also serves as an update to the 2009 NEC and Deloitte report *Advanced Manufacturing in a Networked World: Prospects for a Resurgence in New England*) was to determine appropriate strategies and solutions to capitalize on and sustain growth in the advanced manufacturing sector by working with NEC members, local, regional and state governments, industry leaders, and other interested stakeholders to assess business capabilities, identify barriers to growth, and develop actionable recommendations to address growth challenges.

More specifically, the study was structured to:

- Provide a fact-based analysis of the New England advanced manufacturing industry cluster using primary and secondary data
- Update and refresh the cluster data analysis presented in the 2009 report
- Examine industry growth patterns and emerging or disruptive innovations within the industry
- Complete an analysis of stakeholder needs and concerns by conducting a series of interviews and workshops with manufacturers, educational institutions, state / local / regional government officials focused on economic development, workforce development and education, non-profit industry and economy advocacy groups, and other interested parties
- Articulate common challenges to industry growth, along with complementary opportunities to address them
- Formulate actionable recommendations for public and private sector stakeholders to collaborate with one another in efforts to drive growth
- Raise the profile of advanced manufacturing in New England

Approach

Similar to the approach employed for the 2009 study, a detailed analysis of primary and secondary data was conducted to build a comprehensive picture of industry and labor trends in New England’s advanced manufacturing industry. Data from the U.S. Census Bureau, the Bureau of Labor Statistics, and the Bureau of Economic Analysis, as well as publicly available sources from state agencies and industry organizations were analyzed to determine baselines, detect industry trends, and identify advantaged industry subsectors poised for growth. This data analysis was supplemented with findings collected during interviews and workshops with individuals representing private and public sector interests. Together, quantitative analysis and qualitative review were used to develop insights into barriers to success and opportunities for growth in advanced manufacturing. This combined approach facilitated the development of recommended action steps to spur growth and raise the profile of advanced manufacturing across New England.

To gain a clear understanding of the competitive business environment across the region, the study examined each state’s economy. From a macroeconomic level, location quotients — the percentage of jobs provided by a particular industry in a selected region as compared to the nationwide percentage of jobs in that same sector — were used to identify the advanced manufacturing subsectors that were particularly well-represented in the region. These calculations were combined with an analysis of productivity data to pinpoint subsectors with the potential for economic growth. The team also conducted a microeconomic review of industry clusters that exist to support growing subsectors in the region, as well as capability

clusters that overlay all industry sub-sectors and enhance the region's competitiveness. In addition to identifying industry and capability clusters, the team identified emerging disruptive technologies, or "game changers," that are poised to radically alter the way in which advanced manufacturing firms operate.

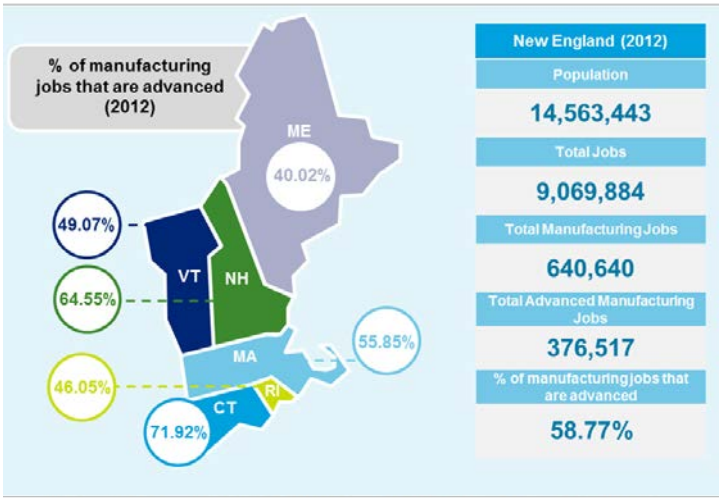
After industry subsectors were analyzed and disruptive technologies identified, the team assessed both the core drivers and barriers to advanced manufacturing growth in the region. These issues included education, workforce development, economic development, business regulation, cross-sector collaboration and industry branding. To validate initial findings and enhance analysis, the study team held interactive workshops and 1-on-1 interviews with policymakers, economists, educators, business advocacy groups, and industry leaders. Through these discussions, the diverse group of stakeholders discussed the region's manufacturing environment and identified key issues that the manufacturers were facing, as well as initiatives that had sprung up to address them.

The final phase of the study focused on developing recommendations for the region to create an actionable economic development strategy to improve New England's competitiveness in advanced manufacturing, increasing the region's ability to grow, retain, and attract firms within the region. These findings and recommendations were based on both the quantitative analysis of available data, qualitative review of information provided by industry stakeholders, and analysis of leading practices nationwide.

Key Findings

1. Where We Are Now: Manufacturing in the New England Region

- New England as a region enjoys a competitively advantaged position with respect to advanced manufacturing, stemming from an intricate network of cross-sector relationships (industry, government, and education) that have evolved over time.
- Advanced manufacturing operates in a complex network of suppliers, skill sets, and innovators. Within the region exists a high concentration of both industry clusters and capabilities clusters that support the various industries.
- Despite the difficulties of the recession, advanced manufacturing has proven to be resilient sector of the economy. The industry has been able to return to, and in some cases surpass, pre-recession levels for shipment value, GDP, and employment while traditional manufacturing has struggled to rebound.



Source: Bureau of Economic Analysis (2012); U.S. Census Bureau; Deloitte Analysis

- The emerging economics of advanced manufacturing further favor New England in that the industry has shifted to that one operates on networks of innovative firms interacting to advance design and production methods and tools while creating quantum leaps in productivity. In this manner, New England's industry is able to ameliorate the high cost of business within the region with the value added by leading research institutions, a sought-after talent pool, and a supportive community of innovators co-located with operations.
- Further, location quotient analysis identified several competitively advantaged industry sub-sectors of advanced manufacturing in the New England region. These "industry clusters" have a high concentration of firms and employees relative to the general economy, and include:
  - **Signal processing, navigation, optics, measurement**

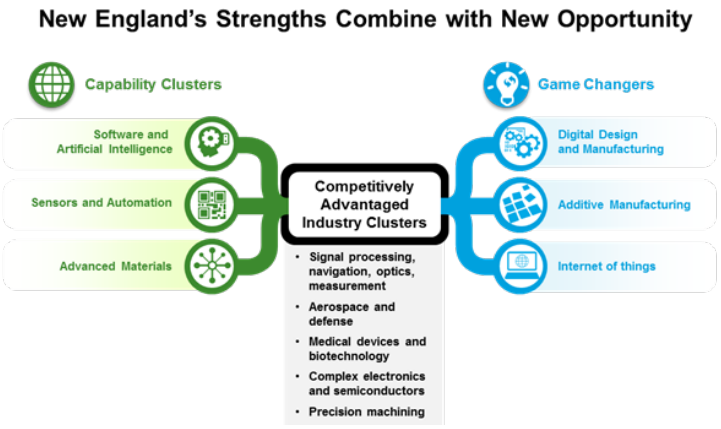
  - **Aerospace and defense**
  - **Medical devices and biotechnology**
  - **Semiconductors and complex electronics**
- **Precision machining**

- In addition to specific industry clusters, New England possesses an umbrella of industry-agnostic "capability clusters" in software and artificial intelligence, sensors and automation, and advanced materials. These differentiate the region in terms of competitiveness and also bolster the firms within industry clusters to further innovate and advance their product.
- Taken together, there is a significant advantage for New England's industry; however, the future is not without its challenges. The region still maintains a sizeable advantage in advanced manufacturing GDP per capita compared to the rest of the country, but the gap is not quite as big as it used to be. Employment and GDP have both rebounded following the recession but recently have begun to stagnate. The obstacles are far from insurmountable; they are, however, very real.

2. Where We Are Going: Game Changers – 'faster, better, smarter'

The rapidly accelerating rate of technological innovation is changing the environment in which advanced manufacturing exists today. Three disruptive technologies have emerged that break traditional economic trade-offs within the manufacturing economy. These "game changers" include: a) digital design and prototyping, b) additive manufacturing, and c) the "Internet of Things" (IoT).

- **Digital design and prototyping** employs advanced software and collaboration tools to allow global manufacturing teams to collaborate remotely on a virtual product before a prototype even exists, significantly reducing time to market, as well as the cost of iterative failure and refinement of product prototyping and development.
- **Additive manufacturing** (also known as 3D printing) liberates production from a traditional mold, model, or dye, and provides seemingly infinite combinations of complexity and variability of product design and construction for an array of commercial applications.
- **The Internet of Things (IoT)**, a disruptive concept with applications well beyond advanced manufacturing, will likely alter the relationship that manufacturers and consumers have with their products and machines. More than just data connections between machines, IoT is about the ability to have cheap and tiny sensors that collect information, share that information with other machines and turn information into action, gathering data along the way that can be used to improve product performance.



Game changers represent a new frontier of productivity and possibility for New England's advanced manufacturers. They are both enabled by the region's industry and capability clusters while strengthening them and opening up new markets for the region. The primary challenge for advanced manufacturers will be how they prepare to seize the opportunities that disruptive technologies represent.

3. How We Get There: Seizing the Opportunity

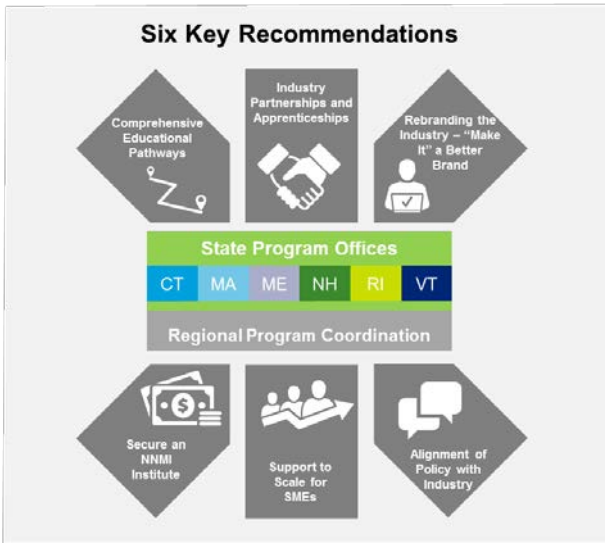
Through the course of our research and discussions we have identified five categories of challenge that are inhibiting advanced manufacturing as an industry from achieving anticipated growth, and at the extreme end, may be costing the region in terms of competitiveness.

- **Education and the skills gap**: There exists today both a dearth of skilled workers qualified to work in manufacturing, as well as an under-skilled labor pool to fill available job vacancies within advanced manufacturing. The aging of the incumbent workforce has brought the need for skilled talent to crisis levels within the industry.
- **SME challenges to scale**: Small and medium-sized enterprises (SMEs) suffer challenges to technology transfer, talent recruitment, and access to innovation tools given their size and constrained bandwidth. These challenges exert a negative influence on the overall industry given SMEs' role in the advanced manufacturing supply chain.
- **Alignment of policy to industry**: Existing programs (most Federally funded) may not have the flexibility to meet the needs of advanced manufacturers in a manner that is timely or user-friendly. Many "islands of excellence" exist to meet targeted training and technical assistance needs, but they alone can't scale to meet the demand for services that is present within the manufacturing ecosystem. R&D tax credits and training funds, although beneficial to larger, established companies, are less applicable to smaller, startup advanced manufacturers.
- **Complex regulatory environment**: More than tax incentives or direct investment by the government, companies expressed a desire to make business regulatory environment more clear, reliable, and predictable during our interviews. Most companies understand the need for government regulation of business, but the complexity of regs and timing for compliance force many to employ separate staff to analyze and process regulatory documentation.
- **High cost of doing business**: High-priced inputs (energy) as well as aging infrastructure (roads, bridges, ports) and tax policies across New England drive up the cost of doing business, and many companies within the region are persistently approached by "lower cost" states with comprehensive business attraction and relocation packages.

Embedded in each of these challenges are a number of related opportunities. The further success of the advanced manufacturing sector will likely depend on a focused and collaborative approach between the private, public, and education stakeholders within the new regional innovation framework.

4. An Action Plan for New England

Through the course of our research and discussions, we have identified six areas of opportunity that, if fully shared and applied across the region, could differentiate New England and serve as accelerators for advanced manufacturing growth:



- **Creating comprehensive educational pathways**: A fully connected system for students beginning in high school through a variety of higher educational institutions, technical education, vocational education, training and even internships and work experience. Credit is fully integrated and connected through all levels on the pathway.
- **Increasing industry partnerships and apprenticeships**: Creating connections implemented and strongly reinforced between industry and educational institutions so that students are not only workforce ready, but new ideas from students permeate the industry, spurring innovation. Reinforce career progression and employee retention through paid internships and apprentice models which earn pay and college credit, leveraging funds available from state and federal grants.

- **Rebranding the industry – "Make It" a better brand**: Moving away from the old view of manufacturing by changing the language we use for it – by calling it the "Maker Revolution" we change the brand of "advanced manufacturing" to reflect the high pay, critical thinking, advanced technologies and designs that define it. Support intake of interested students by helping them enroll in the programs that will support their success in advanced manufacturing.
- **Secure a National Network for Manufacturing Innovation (NNMI) Institute**: Successfully pursuing a future round of Revitalize American Manufacturing and Innovation (RAMI) Act funding to make New England one of the 45 NNMI advanced manufacturing centers in the U.S.
- **Support to scale for SMEs**: Vital to the growth of the maker generation are new ideas and the ability of those small enterprises to come to scale. Entrepreneurs and SMEs require programs/support to allow them to develop and scale, as well as R&D incentives that are accessible small and medium-sized startup businesses as well as IP protection and technical assistance to protect their entrepreneurial investment.
- **Alignment of policy to the needs of industry**: Through collaborative dialogue between industry and government, align existing programs to the areas of greatest industry need and examine ways to improve flexibility of use, ease of access, and increased utility to businesses who utilize them. Using industry's input and requirements, steer emerging policy development towards creative and flexible programs and funding that reduce the cost of doing business, streamline regulatory complexity, and support growth in advanced manufacturing for manufacturers of all sizes.

To achieve maximum effectiveness for the New England region, these recommendations must be implemented in a thoughtful, coordinated manner that minimizes duplication of effort, reflects a regional approach, and leverages the leading implementation practices from each state to the benefit of all. Through the creation of a governance structure such as a regional council of state program management offices (PMO) for advanced manufacturing, the six New England states can work collectively to achieve greater outcomes than each state could acting in parallel.

Conclusion

A coordinated effort across a broad range of stakeholders – industry, government, educational institutions, and others – is necessary to take full advantage of the opportunity to grow. This coordinated approach, has helped stimulate growth in other regions across the country and it can work for New England.

Understanding advanced manufacturing in New England

Defining advanced manufacturing

The demarcation between traditional and advanced manufacturing can be somewhat nebulous. However, a good reference from which to start to differentiate these industries is the President's Council of Advisors on Science and Technology (PCAST) *Report to the President on Ensuring American Leadership in Advanced Manufacturing*:

> Advanced Manufacturing is "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies."[1]

In addition, according to PCAST's Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing:

> "Advanced Manufacturing is not limited to emerging technologies; rather, it is composed of efficient, productive, highly integrated, tightly controlled processes across a spectrum of globally competitive U.S. manufacturers and suppliers. For advanced manufacturing to accelerate and thrive in the United States, it will require the active participation of communities, educators, workers, and businesses, as well as Federal, State, and local governments".[2]

Both of these definitions emphasize new technologies, skills and collaboration, represented by the first "A" in advanced manufacturing, which emphasizes the ***advanced*** nature of the materials, processes and teaming structures required for success. They also rightly infer that so-called traditional industries can and should have many elements of advanced manufacturing.[3] In fact, several of the companies interviewed for this report posited the notion that "…if you are manufacturing just about anything in New England today, you are participating in advanced manufacturing."[4]

[1] *Ensuring America's Leadership in Advanced Manufacturing*, President's Council of Advisors on Science and Technology, June 2011.
[2] *Capturing Domestic Competitive Advantage in Advanced Manufacturing*, President's Council of Advisors on Science and Technology, July 2012.
[3] Simoneau, R. and Wosczyna-Birch, K. "Holistic Definition of Advanced Manufacturing." Abstract, December 2014.
[4] Working Session, Southern New England Technical Advisers, October 2014.

What makes the potential of advanced manufacturing so exciting is not just the technology and materials involved, but how the technology and materials have impacted the way in which manufacturers can gain a competitive advantage. While traditional manufacturing uses scale and labor arbitrage to gain a competitive advantage, advanced manufacturing relies on speed, precision, innovation, and automation to improve the products and processes. Advanced manufacturing puts a premium on a management mindset that continuously improves and rapidly integrates science, engineering and technology into sustainable, environmentally responsive new designs and manufacturing capabilities. The competitive advantage, then, is no longer based on mass production and low skilled operators. For advanced manufacturing, the competitive advantage is in mass customization and highly skilled (albeit fewer) operators.

Advanced manufacturing is an ideology that combines innovative design with advanced materials, advanced manufacturing technology, and superior management methods.

In summary, advanced manufacturing is an ideology that combines innovative design (newer, better, more exciting products) with advanced materials (advanced composites, nanomaterials, green materials, etc.), advanced manufacturing technologies (high-performance computing, automation, PLM, CAD, robotics, etc.) and superior management methods.

The regional advantage in advanced manufacturing

In addition to the skills, innovation and technology elements previously described, advanced manufacturing relies on information, and this element makes the collaborative network that surrounds the industry critically important. An advanced manufacturing industry is regionally advantaged by the depth and diversity of the collaborative network (or “cluster”) that surrounds it. In addition to the industry firms themselves, this integrated cluster includes academic institutions, supply chains, start-up hubs and R&D centers, as well as a supportive political environment. One should note that the strength of the cluster is not defined so much by its geography, as by the relationships that exist amongst its actors.

The New England cluster springs from a rich history in manufacturing, dating back to its role as the birthplace of the industrial revolution in America. Over time, the types of products manufactured in New England have evolved, but manufacturing as an integral and vital driver of economic growth for the region has not changed. Likewise, as these industries matured over time, the trade, creative, and business partner relationships developed within them persisted, now yielding a diverse, interconnected ecosystem of stakeholder networks, each one with breadth and depth in the community. In economic geography, this type of industry agglomeration becomes a nexus for knowledge spillovers that percolate throughout the cluster to yield greater and more technologically sophisticated production than could be accomplished by the firms acting independently. The heyday of the shipbuilding yards and textile mills may have waned, but the highly-skilled, advanced manufacturing networks that evolved from it are poised to have a dramatic impact on the economy in New England.

What we term “industry clusters” are really these networks – labor, supply chain, design, innovation, manufacturers – that connect deeply with one another and drive innovation through the products they create and the processes employed for production. The knowledge sharing that occurs between these firms and institutions while interacting in the normal course of business creates knowledge spillovers that comprise a fertile seed bed for the next cycle of innovation to begin. By taking advantage of the high concentration of skills, jobs, relationships and information that exist within these dynamic network clusters, New England embodies the second "A" in advanced manufacturing : an ***advantaged*** position with the potential to position itself as a global leader in advanced manufacturing.

Sizing advanced manufacturing in New England

To appreciate the influence of New England's advanced manufacturing cluster, one must first understand the current size of the industry:

	NE Region	CT	ME	MA	NH	RI	VT
GDP (billions)	$874.2	$242.9	$53.2	$431.9	$66.1	$51.6	$28.4
Manufacturing GDP (billions)	$92.1	$27.3	$5.6	$44.4	$7.6	$4.0	$3.2
Advanced Mfg. GDP (billions)	$62.6	$19.4	$2.4	$31.2	$5.4	$2.2	$1.9
Total Population	14,562,704	3,590,347	1,329,192	6,646,144	1,320,718	1,050,292	626,011
Total Jobs	9,069,884	2,211,689	797,097	4,225,234	825,524	588,336	422,004
Total Mfg. Jobs	640,640	173,448	55,667	263,705	70,668	41,579	35,573
Total Advanced Mfg. Jobs	376,517	124,745	22,278	147,274	45,619	19,146	17,456

Figure 1: New England Advanced Manufacturing Statistics by State
Source: Bureau of Economic Analysis (2012); Annual Survey of Manufacturers, U.S. Census; Deloitte Analysis

In addition, the following map provides a general overview of the impact of advanced manufacturing on each of the six New England states. Advanced manufacturing jobs account for a sizeable percentage of those manufacturing jobs across New England.

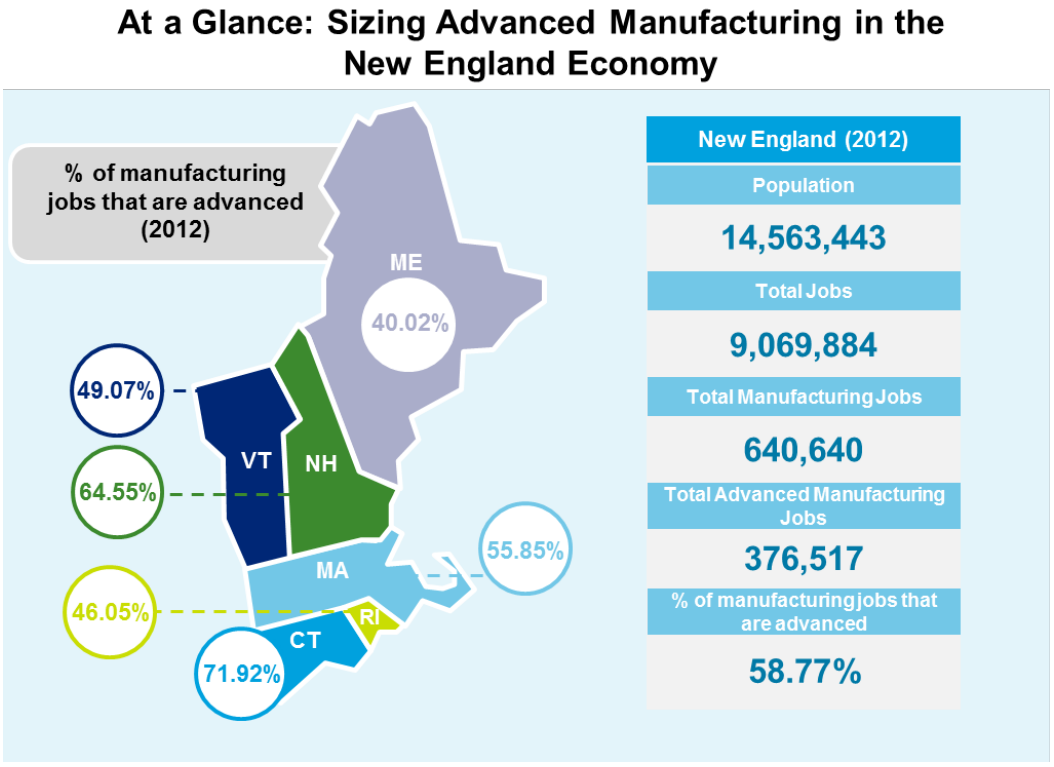


Figure 2: Sizing Advanced Manufacturing in the New England Economy
Source: Bureau of Economic Analysis (2012); U.S. Census Bureau; Deloitte Analysis

The data in Figures 1 and 2 indicates that over half of manufacturing jobs across New England are categorized as advanced manufacturing, representing approximately 4% of the region's total employmenti. Additionally, the distribution of advanced manufacturing jobs as a percentage of total manufacturing appears significant for each individual state, with average salaries for the industry ranging between $70,000-80,000 annually[5]. Additional details on the GDP, jobs and impact of advanced manufacturing in each of the six New England states are located in Appendix A.

Even these high percentages may be slightly underestimated, as it is almost impossible to be a manufacturer in New England without incorporating at least some aspects of advanced manufacturing into the production process or products themselves. Based on analysis conducted by the Manufacturing Institute in partnership with Deloitte Consulting LLP[6], advanced manufacturing jobs carry an employment multiplier of approximately 2.5x jobs in local goods and services, which if applied here, expands the percentage of jobs dependent upon or heavily influenced by advanced manufacturing to 10% of jobs across the region, underscoring the important role manufacturing plays in the careers and lives of working New Englanders.

Industry Growth Trends

While it is instructive to view the current state of advanced manufacturing in the New England region, it is also important to look at trends and indicators of economic growth to assess how the industry has performed over a period of recent years, furthering evidence of its resiliency and staying power. While the drivers of economic growth and the measurement thereof can be debated, we have adopted the measurement variables employed in the 2009 advanced manufacturing report *Reexamining Advanced Manufacturing in a Networked World: Prospects for a Resurgence in New England*[ii], which assessed the following three measurements of economic health:

- **Value of Shipments**: Per employee value of manufacturing shipments or output that reflects both productivity and increased value-add content per worker.[7,iii]
- **Productivity**: State GDP contributions from manufacturing
- **Employment**: Year-to-year change in the number of manufacturing jobs

A focus on productivity gains and value of shipments, in addition to employment growth, is particularly important in the manufacturing industry, where technology and continuous improvement allows for exponential increases in productivity without a correlated increase in jobs. That is not to say that these increases will not lead to job growth, but rather it can account for the lag between productivity gains and the increased employment that will result when those gains are invested back in that industry.

Additionally, an increase in productivity or gross domestic product will increase labor income, business taxes, and capital income, thereby increasing state revenues. While job growth may be ideal from a state's economic development perspective, the other measures should not be discounted as important components of the economy that can be influenced by state policies. In addition to these direct economic benefits, growth in productivity and output signal a vibrant business climate, making the region more competitive overall.

Finally, technological advancement and productivity improvements in the region have made New England competitive in the export market for manufactured goods. The highly specialized products manufactured in the region and its reputation for a high-quality workforce and strong advanced manufacturing base have not only allowed some of the New England states to become export leaders, but have also attracted foreign business investment. If fostered, this growth potential could result in substantial gains for manufacturing in New England.

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[5] *Advanced Manufacturing in a Networked World: Prospects for Resurgence in New England*. Deloitte Consulting LLP and New England Council, 2009.
Jackson, S. *A New Era of Alignment in Massachusetts' Advanced Manufacturing Industry*. Pathways to Prosperity Network and Harvard Graduate School of Education, February 2015.
[6] *The Skills Gap in Advanced Manufacturing: 2015 and Beyond.* Manufacturing Institute and Deloitte, February 2015.

[7] NB: For value of shipments, data was not available beyond 2011 for analysis.

Value of shipments

The value of shipments coming out of manufacturers is a key metric for determining industry health in the region. While advanced manufacturing had been a growing portion of all New England manufacturing for several years prior to 2007, the recession served to only widen the gap between advanced and traditional manufacturing.[iv]

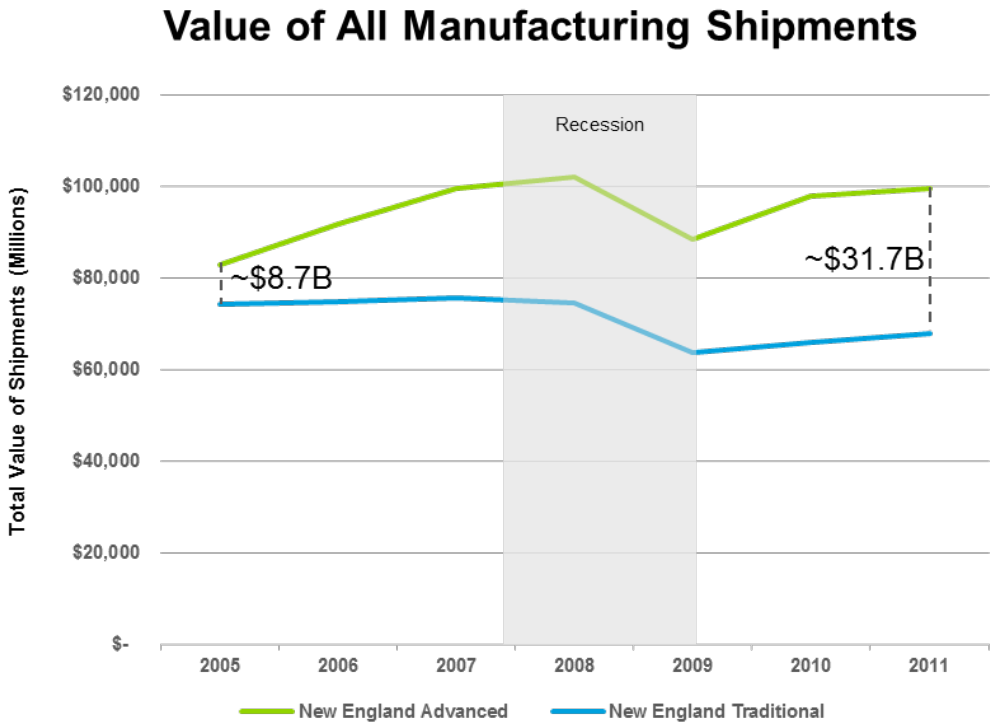


Figure 3: Value of Manufacturing Shipments in New England
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

What started as a gap of $8.7 billion in shipping value more than tripled to $31.7 billion by 2011. Drilling down into advanced manufacturing's growth during this time period, one can see that although the recession did knock progress backwards, the total value of shipments has otherwise climbed upwards at a steady rate for the past several years across the region.

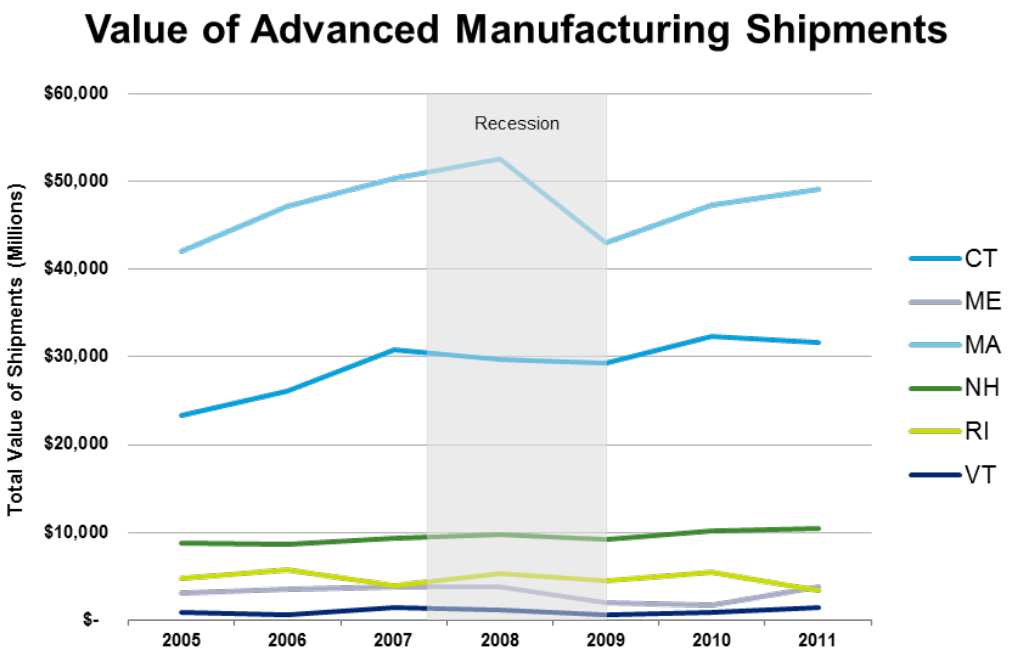


Figure 4: Value of Advanced Manufacturing Shipments by New England State
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

As highlighted in the above graph, this is not an isolated trend either: five of the six New England states saw at least some growth in the value of the advanced manufacturing shipments, with Connecticut leading the way with a 36% increase since 2005. Combined, the New England states saw their total shipment value rise to nearly $100 billion, a 20% increase. Put into broader context, this growth rate becomes even more impressive as it is nearly double the rate of the rest of the country over the same time frame (11%).

A look into shipment values also reveals another important trend: advanced manufacturers are becoming more efficient. The total shipment value per employee (VPE) has seen tremendous growth over the past several years:

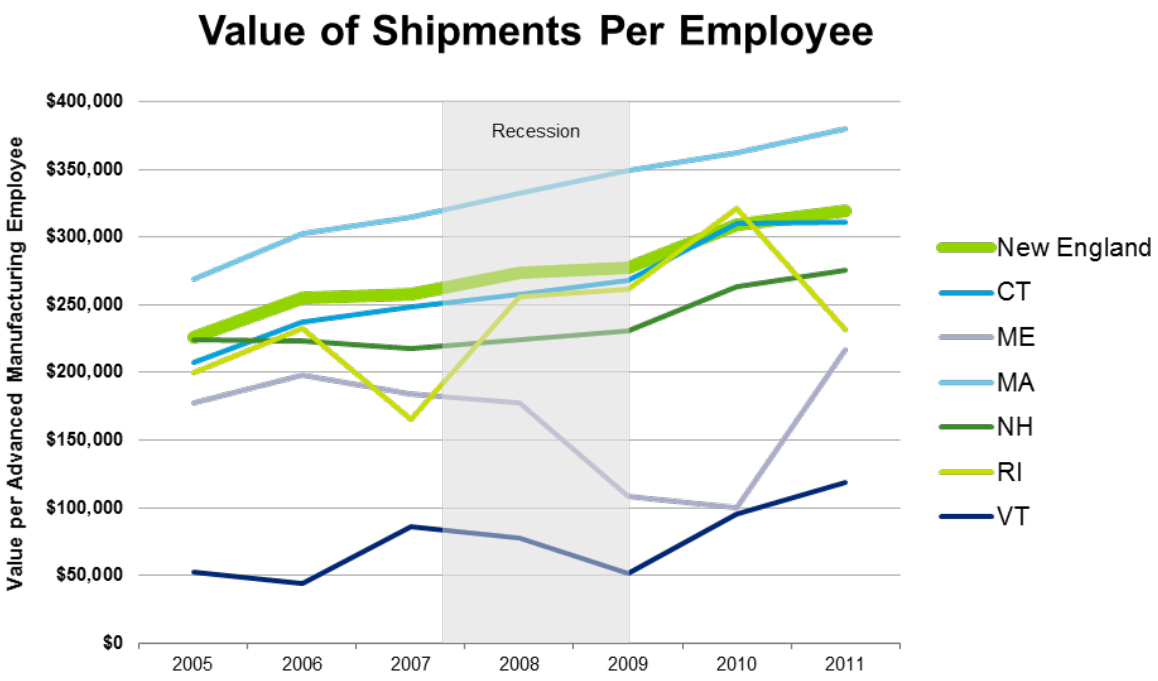


Figure 5: Value of Shipments per Employee
Source: Annual Survey of Manufacturers, US Census Bureau, Bureau of Economic Analysis

While the national average for VPE in advanced manufacturing increased 27% from 2005 to 2011, New England was able to achieve a 40% growth over the same time. Value of shipment is not the de facto metric for efficiency or growth; however, the positive impacts should not be overlooked. Whether it is through automation, innovation, or the cluster's innate advantages, advanced manufacturers in New England are becoming more competitive in the market and that likely means future growth in both sales and new jobs.

Productivity (GDP) growth

Another key indicator for the strength and potential of advanced manufacturing can be seen in historical trends of real Gross Domestic Product (GDP). In the ten-year period leading up to 2012, the contribution of advanced manufacturing increased 12% – particularly impressive when juxtaposed against the 13% decline in real GDP experienced by all other manufacturing subsectors.

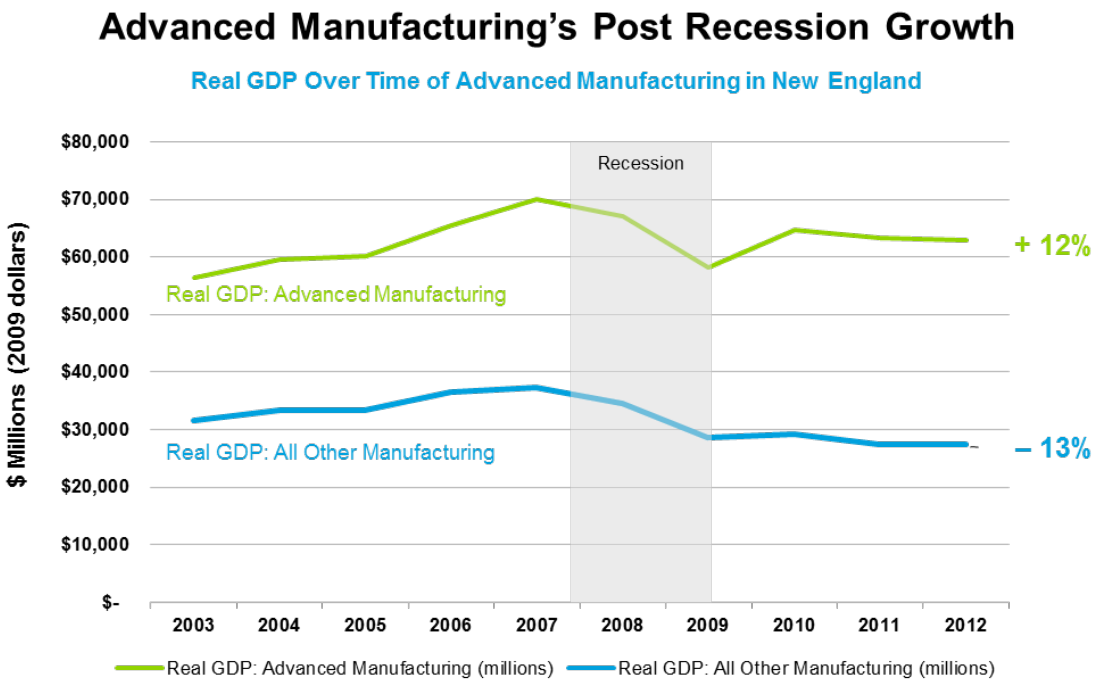


Figure 6: Advanced Manufacturing's Post-Recession Growth
Source: Bureau of Economic Analysis

Figure 6 presents further compelling evidence that not only is advanced manufacturing a more resilient subsector than traditional manufacturing, but as advanced practices are incorporated into traditional manufacturing enterprises, the advanced subsector is also stabilizing growth across both traditional and advanced manufacturing subsectors, supporting the aggregate manufacturing industry as a whole.

When we examine real GDP growth at the state level for advanced manufacturing subsectors since the recession, we see that real GDP has either increased, or remained stable for the majority of New England states, which speaks to the stability of the industry to weather changes in economic conditions.

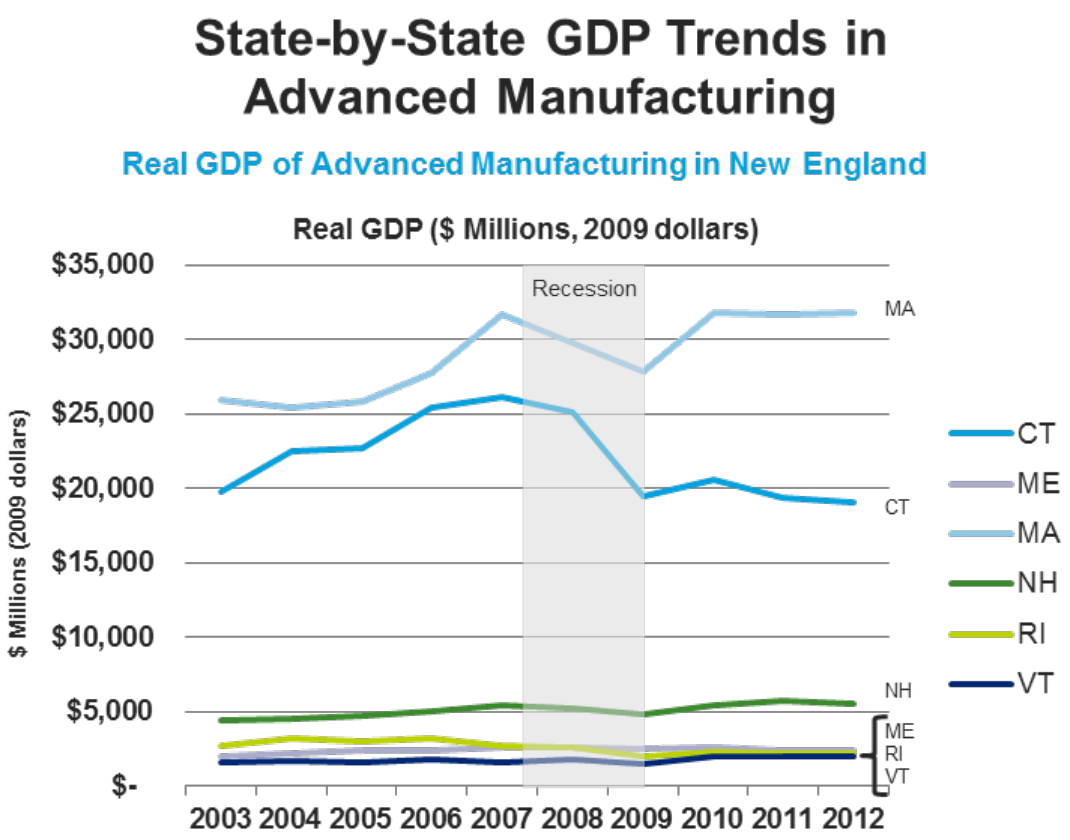


Figure 7: State GDP Trends in Advanced Manufacturing by New England State
Source: Bureau of Economic Analysis

Although Connecticut suffered a significant decline in real GDP during the recession, its overall real GDP level in 2012 remains stable relative to its 2003 level. This decline was likely driven by plant closures in a single subsector (chemical manufacturing) rather than broad cuts across all sectors. Massachusetts also experienced a decline in real GDP as a result of the recession, but its real GDP has since recovered to pre-recession levels.

Looked at from a per capita perspective, the effects of the recession are also masking some other encouraging signs of growth:

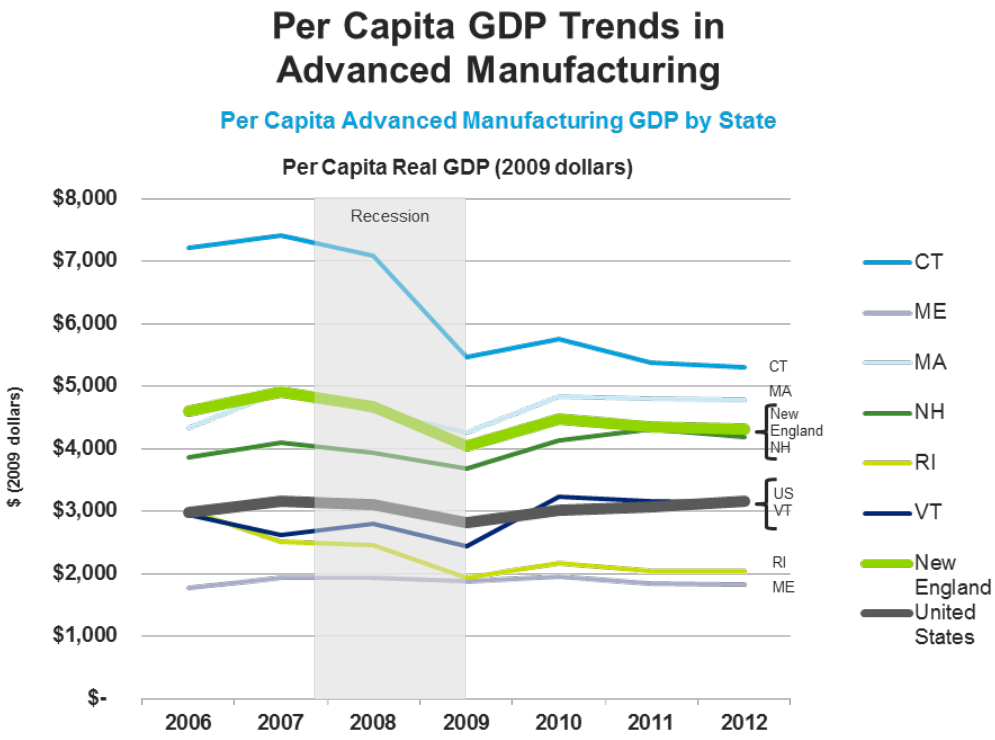


Figure 8: Per Capita GDP Trends
Source: Bureau of Economic Analysis

Overall the region is down slightly compared to pre-recession levels, but both Massachusetts and New Hampshire saw strong growth (11% and 8%, respectively). Furthermore, while Connecticut was hit hard during the recession, it is still the region's leader in per capita GDP; and although the region's lead is not quite as large as it used to be, New England as a whole still outpaces the rest of the country in GDP per capita.

Employment trends

Business growth is certainly important to the overall economy, but the average New Englander is more directly impacted by job creation. In the four year period culminating in 2009, both the traditional manufacturing and advanced manufacturing subsectors in New England suffered job losses of 13% and 11%, respectively. However, when we examine the period following the Great Recession, we see that traditional manufacturing jobs continued to decline and decreased 15% between 2009 and 2012, while the advanced manufacturing subsector experienced a 7% *increase* in jobs during the same time period.

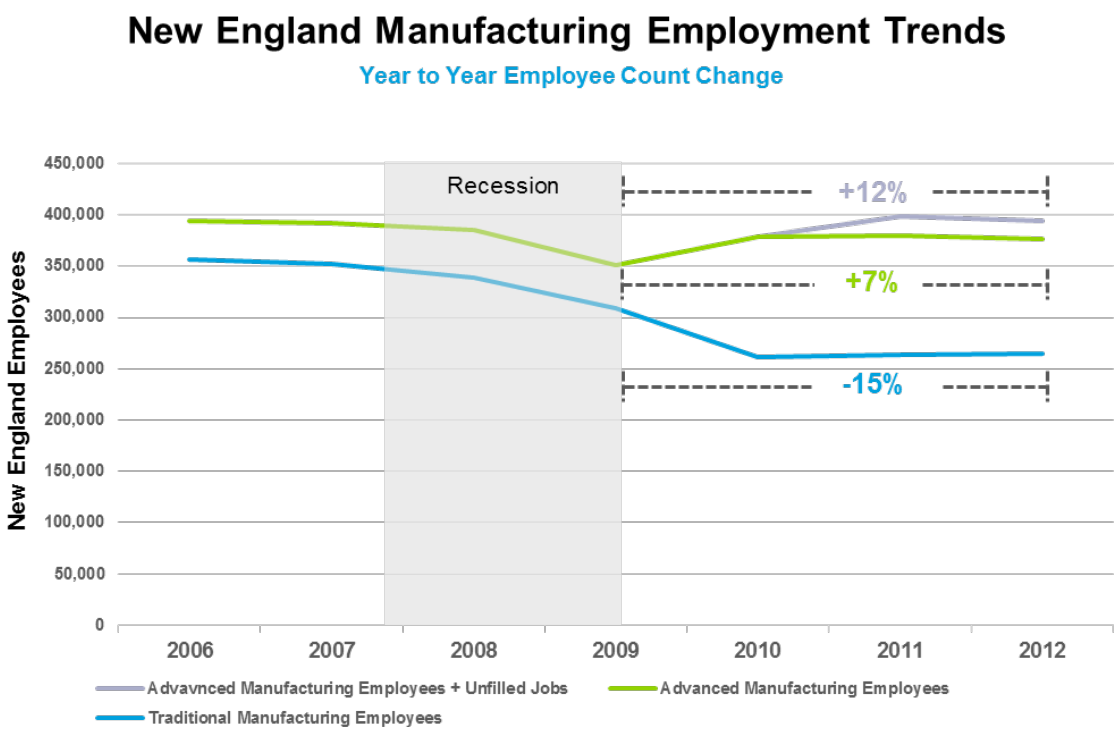


Figure 9: Employment Trends in New England Manufacturing
Source: Skills Gap Report, Deloitte Consulting LLP; Bureau of Economic Analysis, Deloitte Analysis

Additionally, if we take into consideration the 600,000 unfilled manufacturing jobs in the United States in 2011, and extrapolate the data, we can estimate that there were approximately 18,000 unfilled advanced manufacturing jobs in New England in 2011 and 2012.[8] If these vacant jobs were filled in those years, the number of jobs in advanced manufacturing subsectors in New England would have grown 12% between 2009 and 2012. This significant job growth in advanced manufacturing following the recession sharply contrasts with the continued decline in jobs in the traditional manufacturing industry, indicating the resiliency and importance of advanced manufacturing within the New England economy.

Overall Current Outlook

From the analysis above, few clear takeaways stand out:

1. **Advanced manufacturing is a post-recession driver.** Despite the difficulties of the recession, advanced manufacturing has proven to be resilient sector of the economy. Advanced manufacturing has been able to return to, and in some cases surpass, pre-recession levels for shipment value, GDP, and employment while traditional manufacturing has struggled to rebound. This is not to say that traditional manufacturing cannot recover in the region; in fact, there is some evidence to suggest that growth in advanced manufacturing is having a stabilizing effect on traditional manufacturing. Rather, advanced manufacturing's role in driving post-recession growth in the industry is more important than ever before.

2. **Employment expansion could be on the horizon.** If advanced manufacturing in New England is to take the next step, it will likely look to increase its workforce. As noted earlier in this report, manufacturing typically has a lag between productivity gains and increased employment. The rise in value per employee indicates that manufacturers are already seeing those productivity gains. Employment, however, has yet to surpass pre-recession levels. This does not necessarily mean that a hiring boom is due to happen; in fact, the high number of unfilled positions may be an indication that

[8] *The Skills Gap in Advanced Manufacturing: 2015 and Beyond*. Manufacturing Institute and Deloitte, February 2015.

the current workforce does not possess the necessary skills to fuel an industry hungry for expansion.

3. **The future is not without its threats.** Despite the encouraging picture painted by several of these trends, New Englanders should not expect to take the title of the nation's advanced manufacturing center uncontested. The region still maintains a sizeable advantage in advanced manufacturing GDP per capita compared to the rest of the country, but the gap is not quite as big as it used to be. Employment and GDP have both rebounded following the recession but have begun to stagnate in recent years. The obstacles are far from insurmountable; they are, however, very real.

Overall, advanced manufacturing in post-recession New England established itself both as a stable cog of the economy today and a potential driver of significant growth in the future.

Where We Are Now: New England's competitive advantage

While it is helpful to see the broader shifts in New England's advanced manufacturing cluster, macro trends provide only part of the picture. Charting the cluster's path to next level growth requires an understanding of everything that differentiates the New England from other advanced manufacturing regions across the country and around the globe. The competitive advantage for the region lies in the strength of its connectivity within the advanced manufacturing network and between its industry, academic, and governmental stakeholders, which provide an access to intellectual capital and innovation that is not only difficult to replicate, but likewise offsets some of the traditional economic tradeoffs associated with higher cost inputs.

Network clusters tend to specialize in products with historical or complementary ties to the region's assets. For example, the Midwest with its vast tracts of farmland has become a hotbed for photovoltaics, solar, biomass, and renewable energy technology. Texas' advanced manufacturers specialize in products and methods to service the petroleum industry and its oil and gas firms, and Silicon Valley has expanded its capabilities beyond software to service the high-tech sector from a fabrication perspective. New England has its own set of specialized industry subsectors described in detail in the section that follows, and layered over these "hotspots" of specialized industry is an umbrella of differentiated capabilities in software and artificial intelligence, sensors and automation, and advanced materials, which yield a unique competitive advantage as enablers of innovative development across the advanced manufacturing industry.

As the next section demonstrates, few other network clusters demonstrate the geographic concentration of tightly networked expertise in high-demand specializations, as well as the sophisticated capabilities and labor force that enable quantum leaps in terms of product and process innovation. The third "A" of advanced manufacturing in New England centers around the *added value* of network externalities, a value proposition that has the power to offset some of the cost considerations embedded in the economics of traditional manufacturing.

Emerging economics

When setting out to compare the cost of doing business between regions there is more to take into consideration than wage rates, even in traditional manufacturing. Everything from the cost to transport goods, to energy costs, to the costs of doing business (real estate, business fees, regulations) impact where a manufacturer decides to physically set up shop. Advanced manufacturing products in particular require a highly skilled workforce which is usually expensive in any region. Instead of bargain hunting for lower wages, advanced manufacturers can drive costs down through a better conceptual design, automation, and lean operations. These factors enable new manufacturing locations to become cost competitive without low labor wages.

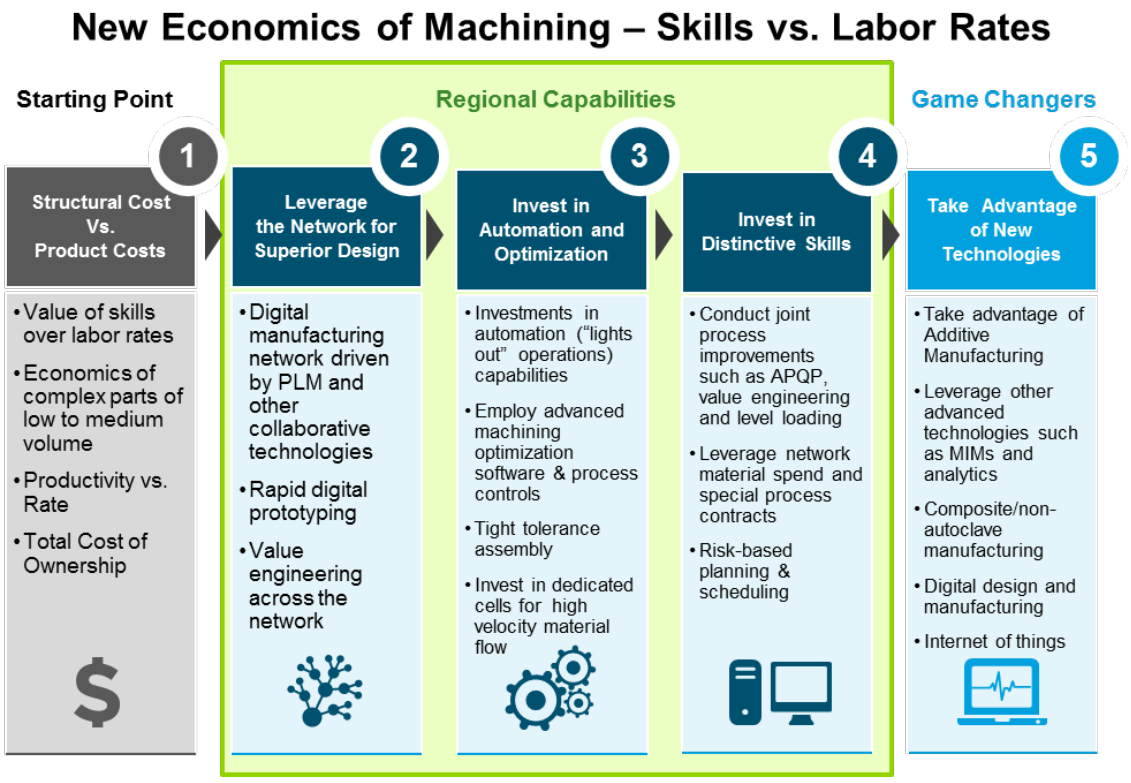


Figure 10: The New Economics of Machining
Source: Deloitte Analysis and Deloitte's Direct Material Database

While most traditional manufacturers of lower complexity products play by the classical economic rule of structural and product costs (1), advanced manufacturers must incorporate additional considerations to their decision-making. By leveraging the network to collaboratively create superior designs (2), product cost can be fundamentally lowered. Note that 60 – 70% is embodied within the design process. The next lever (3), investing in automation, addresses the cost of labor. Instead of focusing on wage rates, automation eliminates labor all together, raising productivity. Finally, distinctive skills and management processes (4) can accelerate the material and information flow in a production system, thereby reducing cost again. In the near future there will be additional game changers (5), which will improve the efficiencies and effectiveness of advanced manufacturing and they will be discussed in detail in a subsequent chapter. Supporting these hypotheses, we are seeing a reverse effect – more and more manufacturing jobs are coming back to the United States from low cost countries and New England is in an advantaged position to capitalize on this.

To demonstrate how New England is poised to compete, we first look at the fixed and labor costs in several regions in New England and compare it to a low cost county with "sufficient" skills in a southern state.[v] In Figure 11 below, the boxes shaded in green are those regions that have a clear advantage for these costs. Those in red are disadvantaged. Glancing quickly, it seems that Boston may not be the best place to start your manufacturing operations and you might be best off going to a low cost county. However, this data only tells a partial story.

Structural Cost Differences New England vs. Low Cost County

	Low Cost County	Boston, MA	Keene, NH	Portland, ME	Burlington, VT	Pawtucket, RI	New Bedford, MA	New Britain, CT
Labor (Avg. Annual Salary)								
Electromechanical Assembler	$39,042	$49,741	$42,225	$41,897	$43,237	$43,925	$43,531	$48,210
Electronics Assembler (general)	$27,421	$35,909	$30,518	$30,597	$31,440	$31,534	$31,175	$35,022
Mechanical Engineer	$82,011	$99,316	$82,099	$82,729	$84,378	$91,019	$90,726	$90,395
Mechanical Design Technician	$55,683	$69,162	$56,627	$57,426	$58,464	$63,078	$62,550	$64,644
Electrical Test Engineer	$85,914	$103,705	$85,947	$86,576	$88,326	$95,076	$94,299	$94,287
Manufacturing Manager	$89,046	$113,024	$92,325	$89,247	$94,752	$101,875	$101,026	$101,630
Estimated Benefits	30%	30%	30%	30%	30%	30%	30%	30%
Real Estate (Lease/ ft²/yr)								
Ind/ WH Avg. Rent	$5.19	$13.95	$7.05	$5.73	$6.00	$5.45	$4.65	$4.49
Office Avg. Rent	$12.05	$37.13	$12.80	$14.95	$17.00	$12.52	$11.28	$14.39
Energy Rate								
Cost per kWh (by county)	$0.08	$0.13	$0.14	$0.13	$0.10	$0.12	$0.13	$0.13
Tax								
Tax Rate-Local plus State	7.76%	11.13%	11.78%	10.87%	11.01%	12.09%	11.11%	13.85%

Advantage | Competitive | Disadvantaged

Figure 11: New England Structural Cost Comparison to Low Cost County Benchmarks
Source: Deloitte Real Estate and Labor Database, Deloitte analysis; Burlington, VT Community and Economic Development Office

To complete the site selection analysis, one must translate those structural costs into real product costs to understand the real cost disadvantages. By taking a sample of product cost structures for medical devices, complex electronics, and aerospace machining (see Figure 12) we were able to quantify the cost disadvantages of New England regions compared to a low cost county in the South.

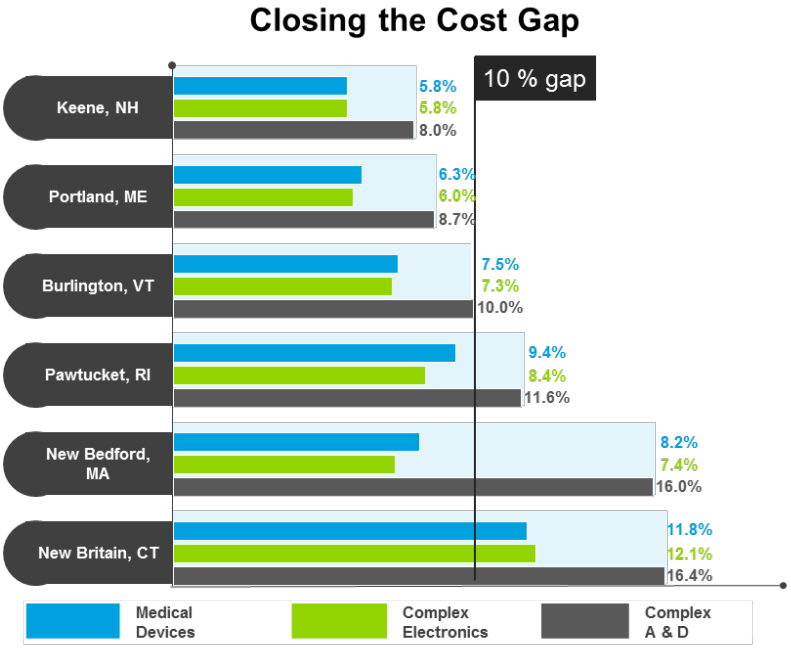
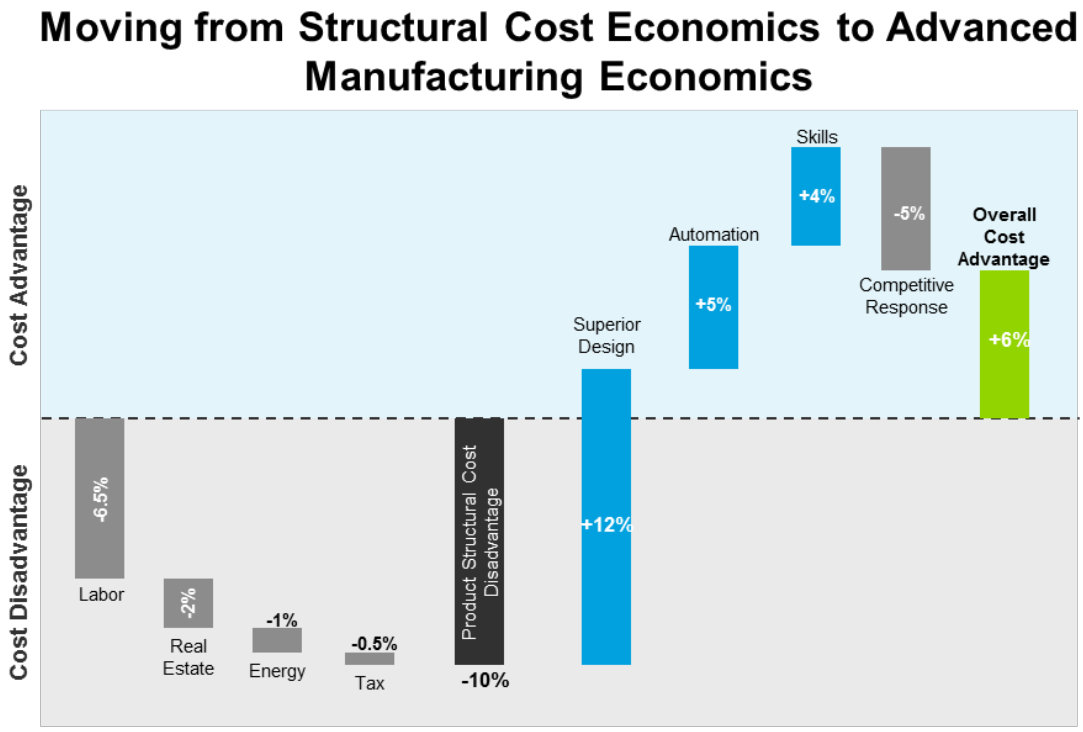


Figure 12: Closing the Cost Gap in New England
Source: Deloitte Real Estate and Labor Database, Deloitte analysis

For these sectors, there is a competitive cost gap of only 5-10% – a gap that can be closed through advanced methods and network cluster advantages. Figure 13 below illustrates how the technologies and management methods of advanced manufacturing can overcome perceived cost disadvantages.



Note: Normally, 70% of product cost results from initial design. Value engineering practices range from 25% during the design cycle and 10-15% cost down for current production products.

Figure 13: Moving to Advanced Manufacturing Economics
Source: Deloitte Labor & Real Estate Database; Deloitte analysis; Deloitte Client Research

In the above figure we start with a 10% cost gap at the product level. Incorporating superior design has the ability to eliminate that gap. This advantage comes from reducing high design costs: an estimated 70% of product cost comes from the initial design process.[vi] The large industry networks in New England, with their ability to collaborate, innovate, and disseminate, have a greater ability to lower design costs than other, less connected regional clusters do. Upfront design savings can pay huge dividends down the production line, making the region competitive with other, cheaper locations.

Adding automation may cause the dual effect of making the cluster more competitive in terms of basic labor costs and increasing the demand for highly skilled workers. These workers, with distinctive skills such as scheduling, manufacturing, engineering, and supplier management, produce further cost advantages for the region. Even as competitors react to these new threats, a New England cluster with high levels of automation and a strong talent pipeline is more than competitive in the market.

In summary, there are several regions in greater New England —the I-91 Corridor, the Down East Corridor of Maine and New Hampshire, and the Blackstone Valley Corridor— that have acceptable cost structures for advanced manufacturing making complex products and/or offering sophisticated services. These cost competitive regions combined with the industry and knowledge hubs concentrated in Eastern Massachusetts can form a very attractive supply chain network, and in many ways create a level of value that offsets if not exceeds the traditional economics of doing business in this mature and otherwise higher cost geography.

Reversing the flow of jobs off-shore

It is one thing to demonstrate how New England can compete against another region in the United States for manufacturing jobs, but when talking about manufacturing, it is impossible to ignore the “declining”

aspect of our four Ds. How can New England compete against Mexico or China when costs such as energy, real estate and wages are so high? Is it possible to not only stem the tide of manufacturing jobs leaving the region, but also bring these jobs back? The short answer is "yes." Since design and technology are so critical to advanced manufacturing, and having close proximity to the skills needed to produce precise and customized products are of relatively higher importance than simple input costs, the US can achieve parity to both Mexico and China through automation.

A New View of Competitiveness

Machining Value Add

Rate	Annual machining value add per employee ($000)	Machining value add per hour worked ($/hr.)	Machining value add per dollar wage	
			2010	2015
US Average	$145	$73.0	$1.93	$2.34
US with High Automation	$240	$121.0	$2.97	$3.44

Rate	Annual machining value add per employee ($000)	Machining value add per hour worked ($/hr.)	Machining value add per dollar wage	
			2010	2015
Mexico Average	$55	$28.0	$3.50	$3.37
China Average	$14	$7.2	$4.49	$3.35

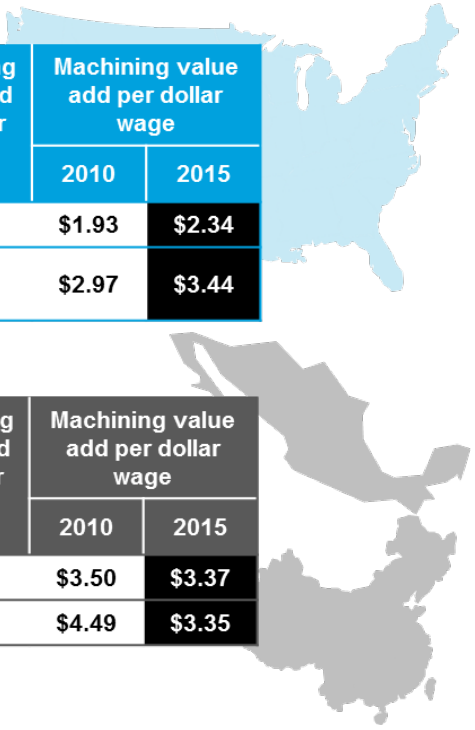


Figure 14: A New View of Competitiveness
Source: Deloitte Structural Cost Database, Deloitte Analytics

Today, China and Mexico have an advantage over the US when considering the pure average machining value added.[vii] However, this ignores two very important points – the impact of high automation required in advanced manufacturing and the fact that inflation is putting tremendous pressure on China's historical low wage advantage.[viii] With high automation, the US has an advantage – even today – with a $3.44 per wage dollar in value add compared to only $3.37 and $3.35 for Mexico and China respectively.

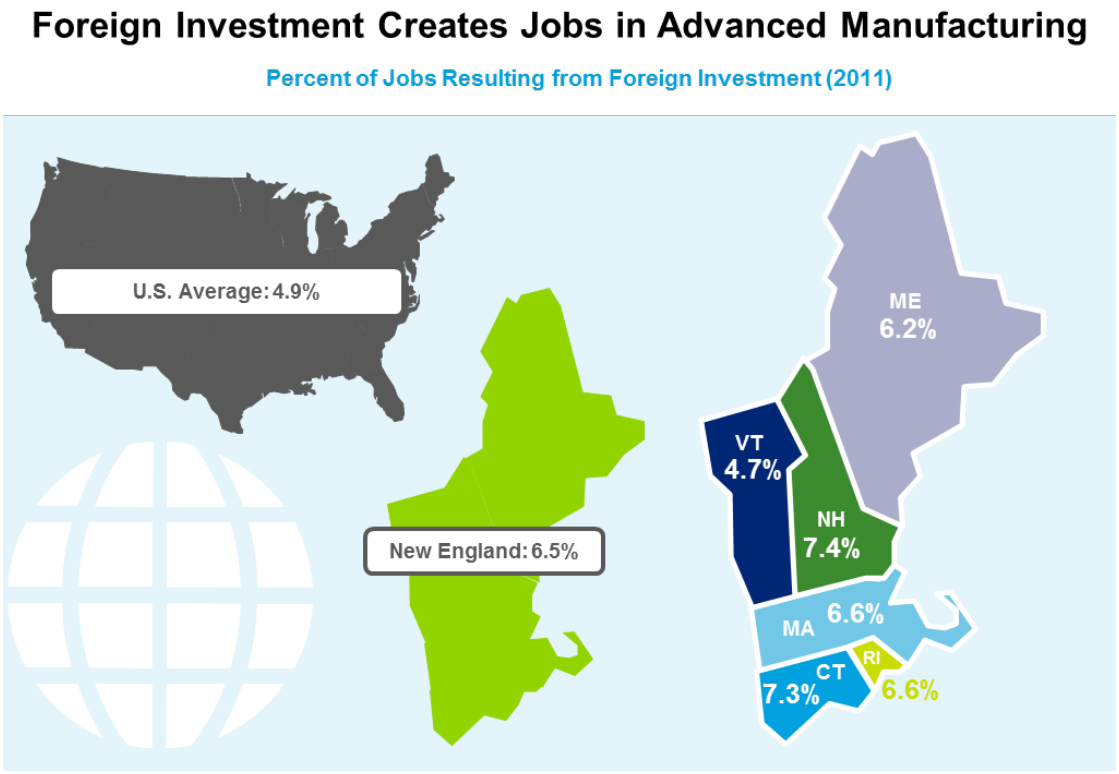


Figure 15: Foreign Direct Investment in New England Advanced Manufacturing
Source: U.S. Department of Commerce

Capital recognizes these global shifts and responds accordingly. Compared to the US average, New England has 6.5% of all jobs resulting from foreign direct investment. Foreign investment in the region's advanced manufacturing sector is an indication that the global market has taken notice of the value creation occurring in New England, the strength of its industry cluster, the productivity of its supply chain, and its talented labor force. As New England's advanced manufacturing cluster matures, the world is taking notice.

It is clear that New England can compete on both the national and international stage in advanced manufacturing. Rather than aiming to compete in every industry, though, New England should look to play in the industries in which it has the greatest capabilities and competitive advantage.

Industry clusters

As we introduced earlier, there is a strong advantage that emerges from relying on a network of deep sector knowledge, skills, and capabilities. While New England is home to a variety of industries that involve advanced manufacturing, we have used location quotient analysis to examine the concentration of jobs in an industry subsector as compared to the national proportion of jobs for that same subsector. In doing so, the data revealed identify industry five clusters of advanced manufacturing where New England has a competitive advantage[ix]:

- Signal processing, navigation, optics, measurement
- Aerospace and defense
- Medical devices and biotechnology
- Semiconductors and complex electronics
- Precision machining

A sample of the companies, location and description of the advanced manufacturing performed in each New England state is included in Appendix A.

By measuring the concentration of certain jobs within a geographic area (New England) relative to that same proportion of jobs on the national scale (United States), location quotients construct an approximate measure of relative economic competitiveness of an industry cluster relative to other geographies. To interpret a location quotient, consider the following values: a location quotient of 1 equates to “average,” while a value between 1 and 1.5 is “advantaged,” between 1.5 and 2 “extremely competitive,” and anything beyond 2 “dominant” in terms of cluster concentration and strength.

A location quotient of 1 equates to “average,” while a value between 1 and 1.5 is “advantaged,” between 1.5 and 2 “extremely competitive,” and anything beyond 2 “dominant” in terms of cluster concentration and strength.

1. Signal processing, navigation, optics, measurement

New England’s signal processing, navigation, optics, and measurement industry cluster is largely composed of defense contractors. The region’s longstanding relationship as a supplier to the United States military, along with prominent military installations within the region, creates a steady stream of procurements promoting innovation in technologies and products that are employed in the nation’s defense – in this sense, advanced manufacturing and the defense industry are mutually reinforcing. Notable companies in this cluster include established multinational firms such as Raytheon, a defense, aerospace systems, and security company headquartered in Waltham, MA, as well as Corning NetOptix, a Corning subsidiary and manufacturer of optical mechanical products and advanced imaging systems, headquartered in Keene, NH. Additionally, the region boasts several leading companies competing in the measurement tools and instruments space, including Perkin Elmer (Waltham, MA), and Waters Corporation (Milford, MA).

As shown below, New Hampshire stands out among the three regional states with notably high job concentrations in this sub-sector. Massachusetts also has a significant concentration of jobs well above the national proportion of 1.0. Additionally, the per capita value of shipments for regional companies significantly exceeds that of the nation as whole, highlighting the strength and efficiency of the cluster.

Regional economic base

2013 Location Quotients - Signal-processing, navigational, optic and measurement tools						
Region 1.70	CT 1.01	ME N/A	MA 1.75	NH 6.83	RI 0.07	VT N/A[x]

Productivity growth

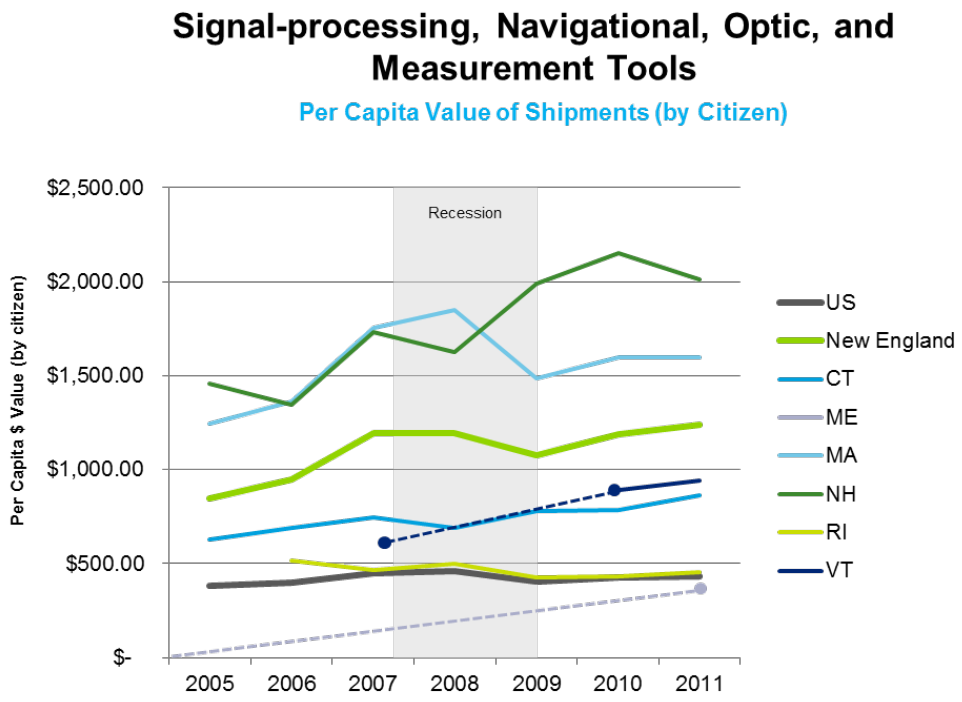


Figure 16: Productivity in Signal-processing, Navigational, Optic and Measurement Tools Cluster
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

Note: Dotted lines indicate missing / unavailable data for the years specified.

2. Aerospace and defense

New England continues to build on its historical legacy as a leader in the aerospace and defense industry. The region has been a hub for shipbuilding dating back to Colonial times, and Connecticut became a major center for aircraft engine production beginning in the 1920s. One of the largest regional players from an aerospace perspective is United Technologies (UTC), a leading producer of aircraft engines, aircraft sub-systems and helicopters headquartered in Hartford, CT, and the parent company of Sikorsky, UTAS, and Pratt & Whitney. With regard to the marine defense industry, two of General Dynamics' largest ship and submarine building subsidiaries are based in New England. Electric Boat has locations in both Groton, CT, as well as Quonset Point, RI, while Bath Iron Works is based in Bath, ME. BAE Systems, a multinational aerospace, defense, and security company which is also one of the world's largest defense contractors, maintains electronic systems locations in Massachusetts, New Hampshire, and Maine. These large institutional companies also support an entire ecosystem of smaller machine shops and parts manufacturers in the region that supply the material components required to build the companies' large finished products.

Connecticut leads the cluster with a proportion of jobs 369% larger than the national proportion, although Maine and Rhode Island have significantly higher job proportions as well. We can also see Connecticut's relative strength in productivity as the per capita value of shipments from the state is roughly 4-7 times that of the United States from 2005-2011.

Regional economic base

2013 Location Quotients - Aerospace and defense						
Region 1.62	CT 3.69	ME 2.35	MA 0.74	NH 0.46	RI 1.66	VT 0.99

Productivity growth

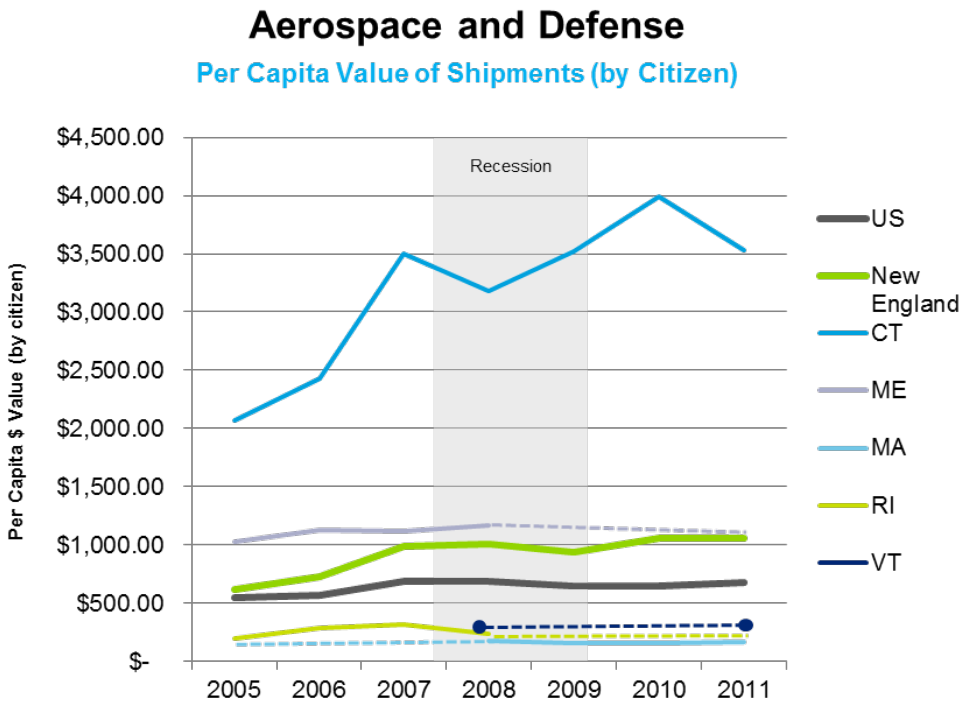


Figure 17: Productivity in the Aerospace and Defense Cluster
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

Note: Dotted lines indicate missing / unavailable data for the years specified.

3. Medical devices and biotechnology

New England is well known as a hub for medical research and innovation, with strong medical foundations in Boston, MA, Providence, RI, and New Haven, CT. This foundation has attracted small and large medical device and biotech manufacturers alike to establish a presence in the area. The region's advanced capabilities in materials sciences reinforces this industry cluster and further solidifies New England's position as a sought after location for medical device and biotech manufacturers. Companies at the forefront of this industry include Boston Scientific, a leading developer and manufacturer of medical devices based in Marlborough, MA, and Biomedical Structures, a leader in the design and manufacturing of medical textiles, headquartered in Warwick, RI.

The region's strength in this industry sub-sector is further evidenced by four of the six New England states having location quotients greater than United States average. Additionally, while the per capita value of shipments from the region as a whole closely matches that of the US, we can see that Massachusetts' productivity significantly outpaces the national per capita value.

Regional economic base

2013 Location Quotients - Medical devices and biotechnology						
Region 1.40	CT 1.83	ME 0.98	MA 1.37	NH 1.11	RI 1.41	VT N/A

Productivity growth

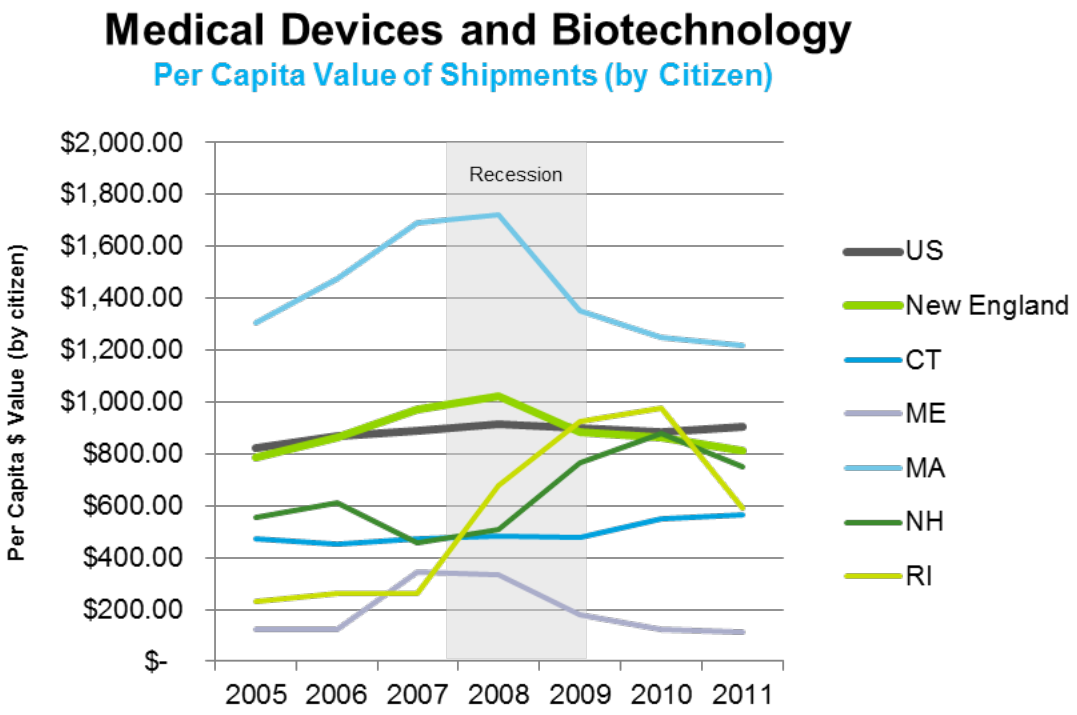


Figure 18: Productivity in Medical Devices and Biotechnology
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

4. Semiconductors and complex electronics

The high tech roots of New England are evident in the continued strength of the region's semiconductor and complex electronics subsectors. Leading manufacturers in this space such as Analog Devices, with a base in Norwood, MA, EMC Corporation (EMC^2) in Hopkinton, MA, and IBM in Essex Junction, VT, require a skilled regional workforce to support the manufacturing of semi-conductors. Other key regional players include Applied Materials, a leading equipment supplier to the semiconductor, display, and photovoltaic industries, with their Research, Development and Manufacturing facility in Gloucester, MA, and Logic Supply, a company designing and manufacturing computers to be used in harsh environments, headquartered in South Burlington, VT.

Vermont is the clear regional leader in terms of job concentration in the semi-conductor and complex electronics manufacturing industry sub-sector, due largely to the presence of IBM in the state. From a productivity perspective, the per capita value of shipments in the region consistently measures well above the US, led by New Hampshire and Massachusetts, both of which display steadily increasing per capita values of shipments in recent years.

Regional economic base

2013 Location Quotients - Semiconductors and complex electrical components/assemblies						
Region 1.90	CT 1.44	ME 0.70	MA 2.20	NH 2.42	RI 0.77	VT 4.17

Productivity growth

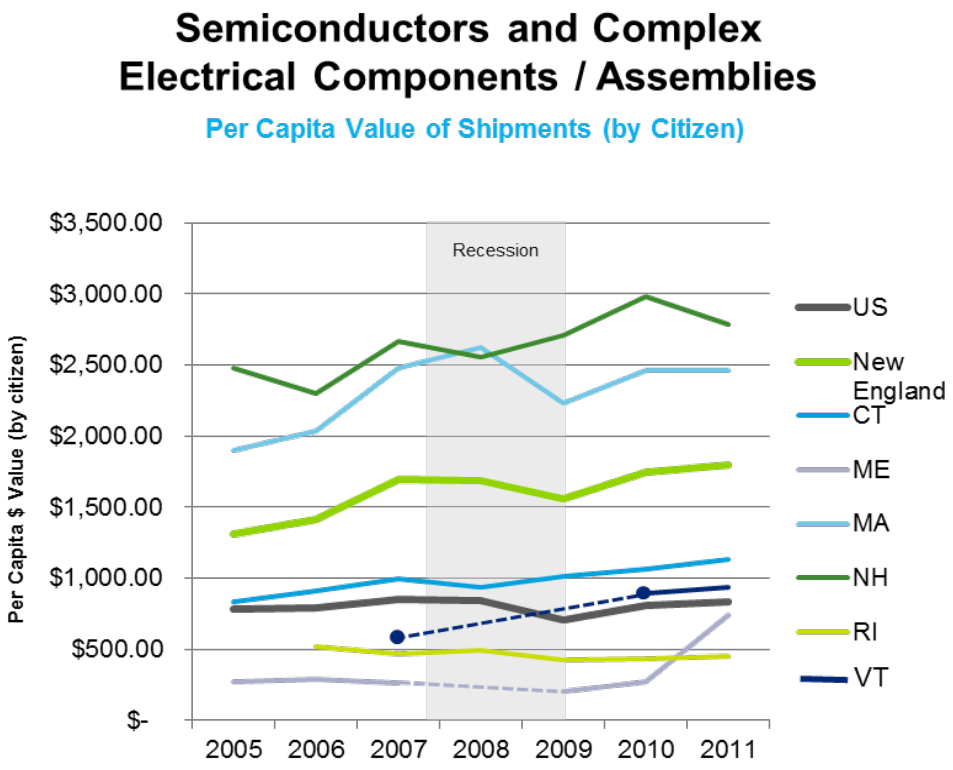


Figure 19: Productivity in Semiconductors and Complex Electrical Components / Assemblies Cluster
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

Note: Dotted lines indicate missing / unavailable data for the years specified.

5. Precision machining

New England has historically been a stronghold for precision machining, but in recent years the industry has declined as a result of companies relocating to lower cost areas and a decreasing regional talent pipeline. Machining is a critical component to the general health of the regional advanced manufacturing industry, as precision machined parts are frequently required as inputs for the finished products of other manufacturers. Several leading machining companies still call New England home, including A-1 Machining Company, located in New Britain, CT, and Birken Manufacturing, located in Bloomfield, CT, both of which specialize in machined products for use in the aerospace industry. Additionally, Baron Machine Company of Laconia, NH, and Hurley Precision Machining of Seabrook, NH, also produce a variety of machined products for use in various industries, including aerospace and defense.

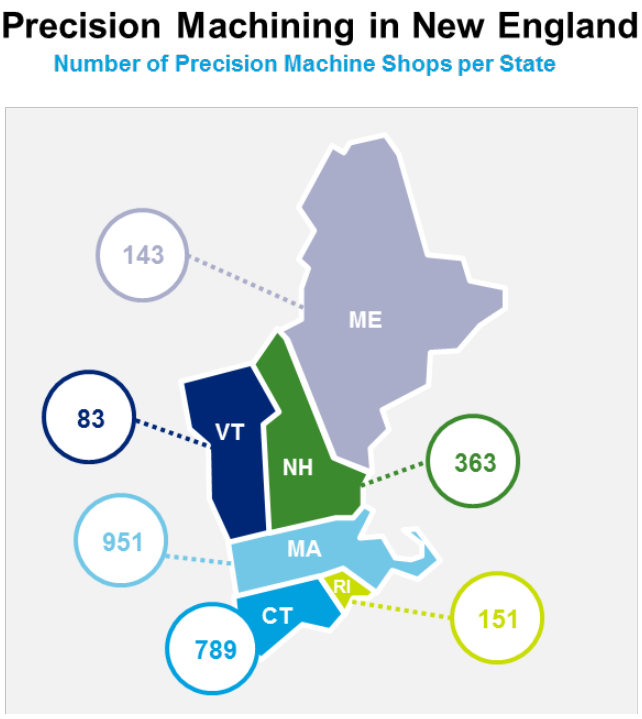


Figure 20: Precision Machine Shops in New England by State
Source: OneSource Global Business Browser, NAICS 3327

While the precision machining cluster is not as robust as it once was, the regional concentration of jobs is still slightly above the national proportion, with strong pockets of concentration in Connecticut, New Hampshire, and Western Massachusetts. Furthermore, New Hampshire's per capita value of shipments is consistently double that of the US, displaying the operating efficiency of the cluster within the state.

Regional economic base

2013 Location Quotients - Tooling and Machine Manufacturing						
Region 1.01	CT 1.24	ME 0.70	MA 0.86	NH 1.93	RI 0.44	VT 1.00

Productivity growth

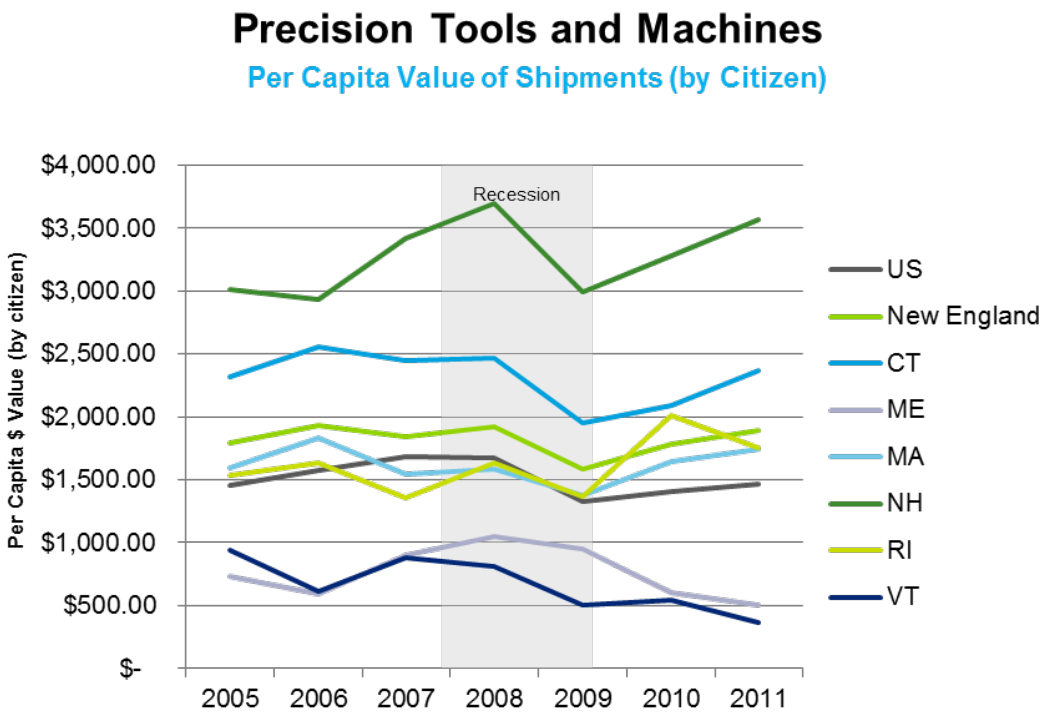


Figure 21: Productivity in Precision Tools in Machines Cluster
Source: Annual Survey of Manufacturers, US Census Bureau; Bureau of Economic Analysis

Industry spotlight

To highlight the diversity of the precision machining industry cluster, a sample of precision machine shops from across the region is highlighted below. These companies are representative of the breadth and depth of the precision manufacturing industry in New England:

CRESCENT AEROSPACE A-1 MACHINING COMPANY	Located in New Britain, CT, Crescent Aerospace, a division of A-1 Machining Company, provides machined products to the aerospace industry. Originally founded as a small parts manufacturer, A-1 now specializes in machining super alloys including nickel-based, cobalt, titanium, aluminum, and several varieties of steel, to be used in large turbine engines. A-1 Machine's in house capabilities enable them to machine parts up to 150" in diameter, weighing up to 10,000 pounds, in addition to tight tolerance thin-walled materials.
AccuRounds Accuracy on the cutting edge.	AccuRounds is a precision machining company located in Avon, MA. Since 1976 AccuRounds has served the medical, defense, aerospace, and semiconductor industries by machining and assembling complex precision turned components. Today, AccuRounds capabilities in CNC Swiss Screw Machining, Turning and Milling, and Precision Grinding are further enhanced through the implementation of lean practices and value stream operations. As a result of their expertise in lean manufacturing principles, AccuRounds was the first North American metal working company to win the Shingo Prize Northeast Silver Medallion.
BARON Machine Company	Since 1957, Baron Machine Company has provided machining solutions for customers from its headquarters in Laconia, NH. Baron Machine's machining capabilities range from creating small precision ground parts to large machinery assemblies over thirty feet long. Examples of end products that incorporate Baron Machine components include satellites, solar panels, Black Hawk helicopters, and F-35 jet fighters. Along with other leading New Hampshire manufactures, Baron Machine has partnered with Lakes Region Community College to design programs providing an Advanced Manufacturing Certificate, and Electromechanical Technician and Advanced Manufacturing Process and Control degrees. Graduates of these programs will fuel the region's future advanced manufacturing workforce.
QUALITY GSP EFFICIENCY RELIABILITY	Founded in 1958, G.S. Precision is a manufacturer of high-precision machine components and sub-assemblies based in Brattleboro, VT. G.S. Precision's principal markets include the aerospace, medical, fiber-optic, automotive, and specialty bearing industries. Due to the growing demand in these markets, G.S. Precision has recently partnered with the Vermont Technical College to form the GSP School of Manufacturing Technology. The two-year program offered by the school will provide accreditation in areas relevant to manufacturing and process engineering, and will ensure that G.S. Precision has access to skilled employees that are essential for growth.

Capability clusters

While the depth of the network in New England's specialized industry clusters positions the region favorably across a diverse set of industries, an additional level of competitive advantage emerges from differentiated clusters of advanced *capabilities*, which are broad cross-sector areas of competency. Capability clusters not only serve the specialized industries identified in the previous section, but also apply to advanced manufacturing more broadly. New England's advanced capabilities include:

- Software and Artificial Intelligence
- Sensors and Automation
- Advanced Materials

While not specialized industries unto themselves, New England's advantage in the capabilities listed positions the region for sustainable long-term growth. Because capabilities are what make advanced manufacturing advanced and take products and processes to the next general level of performance (i.e., employing advanced programming and software, using sensors to automate, innovating product materials), New England's possession of both breadth and depth in these areas adds further to the competitiveness of the region, both for incumbent firms as well as those outside the region.

Software and artificial intelligence

Advanced manufacturers increasingly use software and artificial intelligence (AI) not only to create smarter manufacturing processes, but also as features that are integral to the functionality of their end products. Software is loosely defined as "a set of programs, procedures, and related documentation associated with a computer system; instructions that tell a computer what to do", and artificial intelligence is, relatedly, "a branch of computer science dealing with the simulation of intelligent behavior in computers."[9] The technology innovations made possible through the application of software and AI are used in a variety of

[9] Merriam-Webster definition of software and artificial intelligence, www.merriamwebster.com.

ways. CAD and CAM software are commonly used in the physical product design process and subsequent product manufacturing. Additionally, software can be used to read signals from sensors in the manufacturing equipment and products, and subsequently use the information gathered to automate decision making or trigger notifications about errors or impending malfunctions. Within finished products produced by manufacturers, software and AI enables products to react to their environment or respond to instructions, requiring less human oversight to operate and maintain.

An example of the growing software capability cluster in the region comes in the form of Autodesk's announcement that they will be opening a new project-focused workspace in downtown Boston that will serve as a design and manufacturing hub. While Autodesk currently specializes in creating software for the manufacturing, architecture/engineering/construction, and media and entertainment industries, the goal for the new workshop is to create "innovations in pre-fabrication, the development of imaginative new building materials, and other manufacturing technology breakthroughs". If Autodesk's Boston workspace lives up to the expectations set for it, New England's advanced manufacturers will be well positioned to benefit from these manufacturing related innovations.[10]

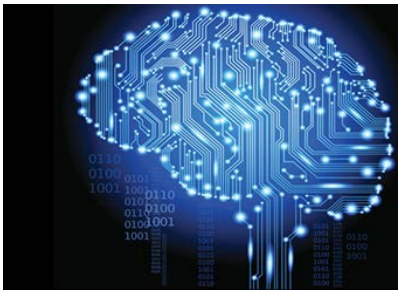
Some examples of the ways in which software and AI are used in New England's capability clusters include:

Signal processing, navigation, optics and measurement	Software is necessary to translate signal outputs into information that can be used for subsequent decision-making.
Aerospace and defense	Software is used in aerospace and defense to monitor the health of engines, and artificial intelligence enables autopilot and autonomous vehicles
Medical devices and biotechnology	Software is needed to read signals transmitted from medical devices that may be implanted in patients to monitor their health and represents the value-add in most medical instruments
Semiconductors and complex electronics	Software is used to test semiconductor circuits and improve potential failure points
Precision machining	CAD and CAM software are used in programs that enable the automation of CNC tools in precision machining

[10] Keohane, D. "Autodesk to open space in downtown Boston, acquires Terrible Labs, funds Robin." *Boston Globe* Beta Boston website, December 2014. http://www.betaboston.com/news/2014/12/16/autodesk-to-open-space-in-downtown-boston-acquires-terrible-labs-funds-robin/ http://betaboston.com/news/2014/12/16/autodesk-to-open-space-in-downtown-boston-acquires-terrible-labs-funds-robin/

Dyn – Software to support decision-making

Founded in 1998 at Worcester Polytechnic Institute and headquartered in Manchester, New Hampshire, Dyn is a "cloud-based internet performance company." The company focuses mainly on analyzing Internet performance and transferring data in a safe and fast manner. Using intelligent software design and deep research capabilities, Dyn is also on the forefront of using the software and AI capabilities to do more than just load balance data across the Internet – they also propose to analyze, connect and balance the internet of things or what Google calls the "physical web".



In the past, you could easily say that "knowledge is power", but in today's data intensive world, knowing what to do with that information is the true power. Companies such as Dyn are allowing other firms to make decisions based on a myriad of data inputs. Moving from pure information technology and into the internet of things is a natural progression and one that Dyn is advocating.

Dyn is a true believer in the power of the New England economy and the region's ability to innovate in the AI / software industry. They are putting their money where their belief is, investing in other local New Hampshire start-ups and building an innovative environment in New England. Even though the company had been around for 10 years, Dyn only took its first round of funding in 2012 for $38 million.

Photo Credit: Dyn, Shutterstock.com

Sensors and automation

The role of sensors and automation within the advanced manufacturing industry is steadily increasing as manufacturers look to automate processes where possible, and closely monitor the performance of their manufacturing facilities. This new reality of manufacturing is made possible by supplementing traditional manufacturing methods with autonomous robots and robotic sensors defined respectively as "robots that capable of performing tasks in the world by themselves, without explicit human control" and "devices used to measure a physical quality, and convert it into a useful signal or data to inform robotic actions"[11]. Use of these technologies holds the potential to mitigate the negative impacts of human error or fatigue, increase manufacturing output and product consistency, and also provide deep insight into the environmental conditions of the sensors being used. These improved efficiencies, made possible through the application of sensors and automation, free manufacturing employees from traditional rote tasks and enable them to engage in the manufacturing process at a higher lever as creative problem solvers.

[11] Bekey, G. *Autonomous Robots: From Biological Inspiration to Implementation and Control.* MIT Press, May 2005. achaney/tmve/wiki100k/docs/Autonomous_robot.html

Some examples of the ways in which sensors and automation are used in New England's capability clusters include:

Signal processing, navigation, optics and measurement	Autonomous robots require a multitude of signal processing instruments, navigation tools, and optics to interact with and move about their environment.
Aerospace and defense	Autonomous robots may be used in the aerospace and defense industry to transport equipment over uneven terrain or patrol areas not safe for humans.
Medical devices and biotechnology	Autonomous and semiautonomous surgical robots can be used to aid doctors in surgeries where very precise and delicate maneuvering is required; additionally, robotic human augmentation can be used to help amputees.
Semiconductors and complex electronics	Autonomous robotic equipment is used in the production of semi-conductors to automate the manufacturing process.
Precision machining	Industrial robots exist for manufacturing purposes that are capable of high speed and consistent production with little need for human oversight.

Going where humans can't go; moving beyond the physical limitations

WildCat, Boston Dynamics' cheetah-based robot that can run up to 28 mph.

Boston Dynamics is an engineering and robotics company that originated as a spin-off from the Massachusetts Institute of Technology. Today, Boston Dynamics is a wholly owned subsidiary of Google, Inc. Historically, the company has principally served defense clients such as DARPA, the US Army, Navy, and Marine Corps, but it appears Google has future plans for the company beyond being a military contractor.

To date, Boston Dynamics has specialized in building advanced robots that use sensor based controls and computation to enable robotic mobility, agility, dexterity, and speed. These robots have frequently been modeled after a wide array of animals, such as a dog, a cheetah, and a flea. Their robots are designed to complete tasks that can't be accomplished by humans due to environmental constraints or physical limitations.[12]

This technology has direct applications in the aerospace and defense and medical devices industry clusters in New England.

Photo Credit: Boston Dynamics

Advanced materials

The development of new advanced materials has huge implications for the advanced manufacturing industry in New England. By using materials that have been engineered to be stronger, lighter, or more conductive than their predecessors, manufacturers are able transform impossible products of the past into the innovative realities of the present. Advancements in materials today frequently occur at the intersection of materials science and nanotechnology. Materials science entails the "study of the properties of solid materials and their applications in manufacturing and construction", and nanotechnology involves "manipulating materials on an atomic or molecular level to form structures on the scale of nanometers"[13]. Advanced materials can enhance existing products by increasing their strength and durability, reducing weight and amount of raw material inputs required, and altering properties such as conductivity and coefficients of friction. In addition to improving existing products, advanced materials and nanotechnology

[12] Markoff, J. "Google Adds to Its Menagerie of Robots." *New York Times*, December 2013.
[13] Merriam-Webster definition of materials science, www.merriam-webster.com.

can also spur the creation of new products made possible by nano-scale engineering, and entirely new materials with unique properties.

Some examples of the ways in which advanced materials are used in New England's capability clusters include:

Signal processing, navigation, optics and measurement	Nanotechnology is used to create smaller sensors and measurement devices that can obtain information from previously inaccessible places
Aerospace and defense	Advances in materials science produce lighter and stronger materials (e.g. advanced composite technologies) that can be used in the construction of platforms (planes, helicopters, boats, and submarines) and large subsystems (turbofan engines, avionics, landing gear, etc.)
Medical devices and biotechnology	Nanotechnology can be leveraged to aid in medical diagnostics and early disease detection through miniature devices implanted in the human body; nano-based therapies can be used for cancer treatments
Semiconductors and complex electronics	Materials science is a critical component of semiconductor manufacturing, as various materials are used for their different conductive properties
Precision machining	New materials created through advancements in the materials science subsector are often machined to create the desired end product (e.g. memory metals and advanced composites)

By continuing to extend the reach of manufacturing's current capacity, capability clusters represent another differentiated area of performance that positions New England favourably within the competitive landscape of advanced manufacturing. Under this umbrella of capabilities, New England's advantaged industry clusters are enriched in terms of their breadth, depth, and novelty, both for the demands of today, as well as those emerging on the horizon.

Where we are going: Game changers – “faster, better, smarter”

The pace of change is increasing and so it is highly likely that the next five years will see more dramatic changes than what occurred in the last two decades. This exponential innovation curve reflects the fourth “A” in advanced manufacturing – the A that stands for ACCELERATING. We have identified three “game changers” in manufacturing that are disrupting the industry and will, as a result, open up new opportunities. These disruptive technologies, when combined with the industry and capability clusters that advantage New England’s advanced manufacturers, create a mutually reinforcing environment that positions the region favorably to act as a leader in advanced manufacturing’s “next wave” of innovation.

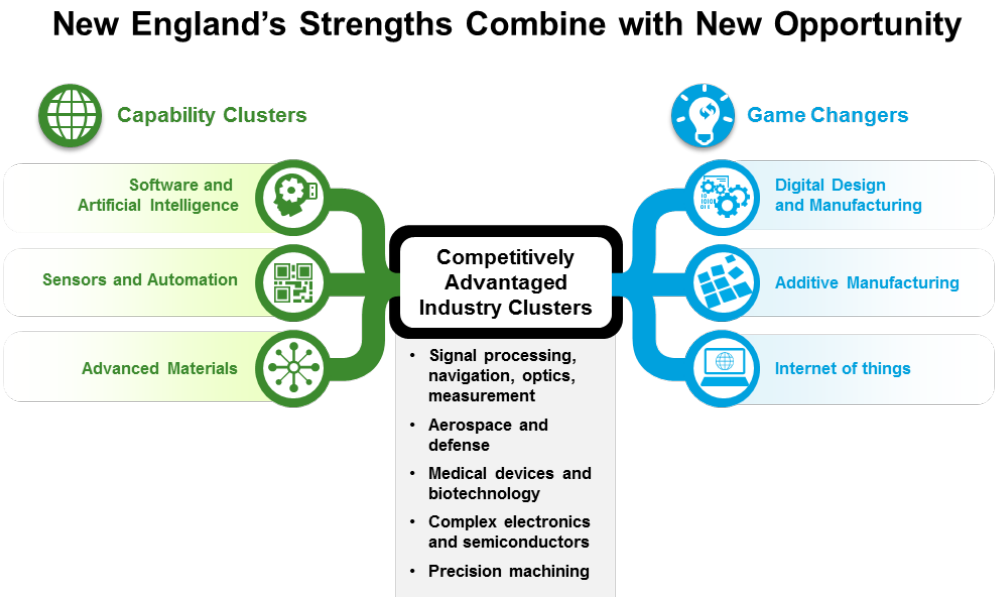


Figure 22: Combining Strengths with Game Changers to Realize Opportunity

Faster: Digital Design and Manufacturing

The expectation of digital design and manufacturing is to produce high quality products with improved designs that can be more easily manufactured and serviced at a competitive price, all while beating the competition to market. In other words: “faster-better-cheaper.” More recently, it has become more affordable and therefore more widely accessible. The tools of digital design can now be found in the hands of the small and medium-sized enterprises and the start-ups that are the engines of growth.

Digital design and manufacturing now links design and planning to the shop floor and allows the manufacturer to better engage through collaborative design and problem solving. By using 3-D visual technology, such as that used by Raytheon (see inset below), companies can work together to produce higher quality and highly manufacturable designs.

Raytheon's Immersive Design Center: Creative fires burn bright in "The Cave"

Raytheon Company is a technology and innovation leader specializing in defense, security and civil markets throughout the world. At its Andover, MA missile center, Raytheon has built a tool for assembling and inspecting highly complex and large products – the Immersive Design Center.

"The Cave," as it is affectionately termed by the scientists and engineers that work with it, has an eight-foot-high stack of 72 ultrahigh-definition television sets arrayed in a 320-degree panorama, featuring 3-D technology with highly realistic views.[14]

In the Cave, Raytheon and its suppliers can see how a product such as the Patriot missile system is coming together, from the assembly of a multi-ton command truck to the shape of a tiny component such as an electronic circuit. Multiple users can be in the center at the same time – even remotely – and see how their work is being integrated with others' work and the project as a whole.

The technology allows people to solve complex problems more efficiently, to literally "see" what the problems might be. As Bill Tice, an engineering manager at Raytheon stated: "In 3-D, you can literally dive in, look under it, around it, take it apart, and put it back together. We're getting designs that are more efficient and easier to produce." In addition, Tim Glaeser, the VP in charge of the Patriot program succinctly stated, "If we put the right people in this room, they'll solve any problem." Different people with different perspectives and areas of expertise can all access and see the same product and tweak it based on their views. Raytheon calls this the "common language of visualization."

Raytheon's Immersive Design Center reduces the time required to develop a product by enabling users to view multiple product components in three dimensions and to explore problems in a collaborative and virtual environment. In this way, the Cave exemplifies the game-changing nature of digital design in manufacturing.

Photo Credit: Raytheon

The potential benefits of this new digital technology are manifold:[15]

1. Faster product development, time to market and production ramp-up
2. Digital link between design, fabrication, and controls engineering
3. Reduced prototyping and physical mock-ups with virtual simulation
4. Improved collaboration and joint problem solving with the consumer and supplier network by providing joint access to design, production, and quality processes
5. Validation of manufacturing processes, resources, and work cells through simulation
6. Visibility into supplier factories
7. Higher initial quality and reduced cost by validating production processes and design for manufacturability
8. Work instructions and shop floor documentation, automatic generation of controls logic, and material flow planning
9. Performance reporting and metrics for continuous improvement
10. Data aggregation across the product life cycle

With President Obama's 2014 announcement of the Digital Manufacturing and Design Innovation (DMDII) Institute in Chicago, we can expect an increase in investment and research, focused specifically in three areas: Product Life Cycle Management, Digital Design and Prototyping, and Digital Manufacturing and Visualization. These digital enhancements are already making an impact on the industry clusters in New England, as discussed in the section that follows.

[14] Adams, D. "Now Showing at Raytheon: Missiles in 3-D." *Boston Globe*, November 2014.
[15] Browne, J. *Integrating Product Design and Development Environments*. Tech Clarity Inc., 2014.

Product Lifecycle Management

Product Lifecycle Management (PLM) is an integrated, enterprise software platform comprised of people, processes/practices, and technology for all aspects of the life of a product and related services from design concept to retirement. PLM leverages a broad range of software applications from CAD, CAM, and CAE for design, prototyping, and manufacturing, to product data management (PDM) that provides consistent information to enable optimal decision making, to digital manufacturing that uses simulations and factory visualization tools to test production processes, and to manufacturing execution systems (MES) that drive the next generation of lean thinking and process controls.[16] A PLM system can greatly enhance collaboration with sales, marketing, supply chain, manufacturing and field services.

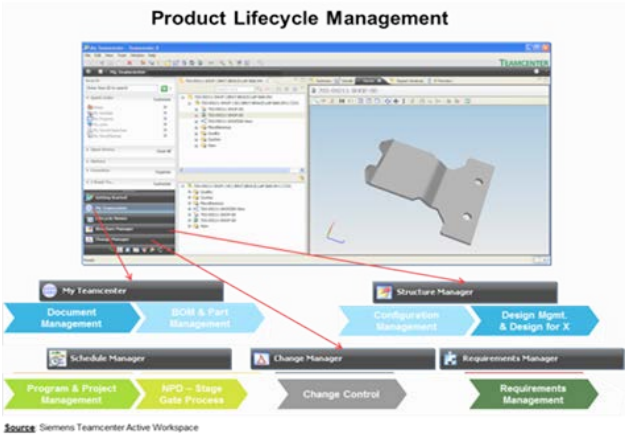


Figure 23: Product Lifecycle Management
Source: Siemens Teamcenter Active Workspace

Some of the most well-known and widely available PLM solutions available in today's market have been tailored to specific industries they serve and have historically targeted large companies. But what about small and medium size companies (SMEs) which comprise a significant portion of an OEM's supply chain? Since most OEMs outsource a majority of their manufacturing to these smaller firms, most of which have highly specialized manufacturing technologies of their own, a PLM deployment gap has emerged, making it difficult to collaborate across platforms. Today, however, new cloud-based systems can lower the cost of PLM and make the system quick to deploy for these smaller firms. PLM cloud computing helps SMEs avoid tying up capital in IT and frees them from IT infrastructure management and demand planning, giving them the ability to come online to a collaborative environment.

New England industry executives have observed they innovate in global teams but can't see the impact of what others are doing. For example, they may have an OEM designer in Connecticut changing the shape of a housing assembly; at the same time, an engineer from a SME is using old data to analyze heat exchange, and a partner in Mexico is designing a wiring harness that may unknowingly interfere with the new housing design. They are blind to each other's changes and unwittingly creating problems for each other and eroding efficiency. However, if the supply chain used the new online collaborative environment capabilities a cloud-based PLM, all partners could connect confidently to a real-time 3-D virtual prototype with a common database (regardless of functions or locations around the world), and effectively collaborate to validate the OEM design.

Collaboration using digital design and prototyping

In order to innovate quickly, a manufacturer needs a rich set of ideas from a broad spectrum of individuals within and external to the company. A single company does not hold a monopoly on great ideas. The power of a supply chain network has the ability to generate exceptional ideas, but needs a collaborative platform to validate them. Digital design and prototyping can provide that platform.

[16] "Connecting the Digital World with the Factory Floor", *Manufacturing Engineering*, April 2014.

Digital Design and Prototyping gives R&D, conceptual and detail design engineering, manufacturing, suppliers, sales and service departments the ability to virtually explore a complete product before it is built. Digital Design goes beyond simply creating product designs in 3-D. It gives product development teams a way to assess the operation of moving parts, to determine whether or not the product will fail, and see how the various product components interact with mechanical and electrical subsystems. By simulating and validating the real-world performance of a product design digitally, manufacturers often can reduce the number of physical prototypes they need to create before a product can be manufactured, reducing the cost and time needed for development.

Figure 24: Digital Manufacturing
Source: Autodesk Manufacturing, Prototyping Q&A

Digital Prototyping changes the traditional product development cycle from design-build-test-fix-build to design-analyze-digitally test-build. Because the geometry in digital prototypes is highly accurate, companies can catch design problems up front so that manufacturers and suppliers could experience fewer engineering changes downstream. Companies can also test design iterations quickly to assess whether they're over- or under-designing components.

In summary, advanced manufacturers should create a joint design space where engineers from any location can change their design in 3-D while others can see what they are doing and make adjustments real time.

Digital manufacturing and visualization

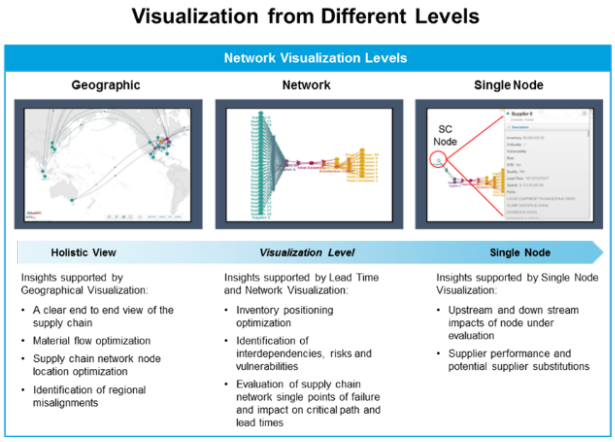
Digital manufacturing using simulations and visualization tools can validate manufacturing processes, essentially linking product design to the shop floor makers of the product. Digital manufacturing extends visualization and virtual modeling into production equipment and automation systems and controls before the production line even exists, allowing lean manufacturing and six sigma methods to be incorporated into the development of the production flow line.

Digital manufacturing can also be applied to detailed work instructions to include tooling and fixtures, as well as assembly sequences and ergonomic considerations for machine operators and assemblers. In summary, digital manufacturing allows manufacturing engineers to simulate the complete manufacturing environment and to optimize production in advance of any physical implementation.[17]

Visualization technologies can also synchronize manufacturing across the entire supply chain. In the schematic featured, companies using advance analytics and visualization tools will be able to:

- See the complexity of their supply chains
- Focus on supply nodes for risk to include prospects for late delivery or quality issues
- Target parts for cost improvement
- Assess performance using real time metrics

[17] "Gaining Competitive Advantage Through Digital Manufacturing", *ARC Insights*, March 2006.



Digital design and manufacturing transforms a formerly manual, human capital-intensive collaboration process into a digital enterprise that is accessible to a global team in real time. In doing so, this game-changing technology reduces the prevalence of costly missteps, proactively identifies what would formerly have been expensive sunk cost mistakes, accelerates time to market, and broadens the field of ideas from which they can draw inspiration.

Figure 25: Digital Visualization Layers
Source: Business Performance Visualization and Analytics, Deloitte Consulting 2012

Better: Additive manufacturing

Additive manufacturing (AM), more popularly known as 3-D printing, describes a group of technologies used to produce objects through the addition, rather than the removal of material[18]. AM was first used commercially in the mid-1980s for the creation of prototypes, models, and visualization tools. More recently, however, advances in printer and materials technology have allowed AM to expand to applications such as tooling[xii] and end-user part production.[19] AM is used in many industries, including aerospace and defense, automotive, consumer products, industrial products, medical devices, and architecture. The overall market size for the AM industry is estimated to be over $3 billion with an annualized growth of 35% over sales of $2.3 billion in 2012. The total market for end-use products (not prototypes and tooling, but production parts) manufactured by service providers using AM was $798.4 million in 2012.[20]

AM is transforming advanced manufacturing

AM is a technology innovation whose disruptive potential is derived from its ability to break existing performance trade-offs in two fundamental ways: first, AM reduces the capital required to achieve economies of scale, and second, AM increases flexibility and reduces the capital required to achieve scope.

- **Capital versus scale**: Considerations of minimum efficient scale shape the supply chain. AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the entry barriers to manufacturing for a given location.
- **Capital versus scope**: Economies of scope influence how and what products can be made. The flexibility of AM facilitates an increase in the variety of products a unit of capital can produce, reducing the costs associated with production changeovers and customization as well as the overall amount of capital required.

Changing the capital versus scale relationship has the potential to impact how supply chains are configured, while changing the capital versus scope relationship has the potential to impact product designs.

Additionally, companies that incorporate AM into their manufacturing process have the potential to enhance their products in the following ways: increased geometric complexity, decreased system complexity, increased customization, and enhanced performance. The first three enhancements illustrate how AM enables new product design. The last highlights how the three enhancements improve performance relative to products or geometries manufactured with conventional techniques.

[18] Crane, J. et al. *3D Opportunity for End-Use Products*. Deloitte University Press, 2014.
[19] "A Brief History of 3D Printing." T. Rowe Price, *Connections, 3D Printing*, May 2012.
[20] *Wohlers Report 2014: Additive Manufacturing and 3D Printing State of the Industry*. Wohlers Associates, 2014.

Increased geometric complexity, or "complexity is free"

The scope capabilities of AM allow manufacturers to create objects that cannot be manufactured using conventional manufacturing techniques such as casting, forging, and subtractive machining.[21] AM allows for greater geometric complexity because material is added layer by layer during the object build process. Layering allows for structures that are difficult, and in some cases impossible, to produce using conventional techniques. Such structures might include curved channels, embedded lattices, and totally enclosed volumes. Geometries such as these are available because structures that will be fully covered in the final object are open and accessible as each layer is created. AM's ability to create complex geometries is enhanced by its capacity to employ temporary support structures during the build process. After production, these structures may be removed through a variety of methods depending on the technology and materials being employed.

An innovative example of AM conquering manufacturing complexity was provided by researchers in the European Union using AM to manufacture custom cranial implants (see inset).[22] In this application, AM's capacity to create complex geometries is leveraged to create bone-growth-promoting lattice structures that cannot be produced using conventional manufacturing techniques. The complex lattice structure can also be filled with a bioabsorbable polymer that promotes bone growth, adding an innovative level of utility to the form and function of the implant.

3-D printing the human skeleton: Oxford Performance Materials (OPM)

Founded in 2000, OPM is a South Windsor, CT-based manufacturer with a simple mission: to exploit a highly advanced molecule called poly-ether-ketone-ketone (PEKK). The company's product line includes a combination of aerospace & industrial parts, biomedical raw materials, and biomedical devices, such as the cranial implant depicted.

Utilizing Additive Manufacturing (AM) capabilities, OPM employs its proprietary OsteoFab® process to produce medical implants to the specifications required by the surgeon by printing from an MRI or a CT scan and constructing the device layer by layer using OPM's OXPEKK®-IG polymer formulation. Weighing less than traditional implants made of titanium, AM implants created with OsteoFab® technology also demonstrate high strength and can be designed to withstand pressure greater than 100 megapascals with minimal deflection.[xiii]

However, this technology allows OPM to go beyond merely replicating shapes for the implant: the company also has the ability to meet specific performance requirements as anatomically applicable. Through a proprietary "Coherent Implantology Process", fit, form and bio-function are digitally calculated, constructed, and then produced.

AM-created PEKK implants offer other advantages besides customizability that improve their function for the patient recipient: improved tissue response to the adjacent native bone, which can lead to superior long term fixation to the skull; lower thermal conductivity, which results in less long-term discomfort for the patient; and, finally, greater transparency to CT, X-ray, and MRI scans, allowing doctors to use conventional imaging techniques after a surgical procedure.[xiv] These functional advantages are accompanied by a number of production advantages, including shorter production time and lower costs for the patient.[xv] Through novel applications of AM, OPM is demonstrating what this game-changing technology can do to improve the lives of individuals.

Photo Credit: WonderfulEngineering.com

Decreased system complexity, or "no assembly required"

The previous example illustrates how AM can be used to create more complex geometries than are possible with conventional manufacturing techniques. Paradoxically, the ability to produce individual components with more complex geometries allows designers to produce entire systems using fewer subcomponents, reducing complexity at the system level. The layering approach of AM allows the

[21] Atzeni, E. and Salmi, A. "Economics of Additive Manufacturing for End-Usable Metal Parts," *International Journal of Advanced Manufacturing Technology* 62, no. 9, 2012.
[22] ASM International, "Technical Spotlight: Additive Manufacturing Used to Create First Laser Sintered Cranial Implant Geometry," *Advanced Materials and Processes*, September 2012.

simultaneous fabrication of internal subcomponents and outer layers. This ability, when fully utilized, can help create "single component systems"—systems that have been redesigned to be produced in a single part rather than by combining subassemblies.

Testing performed by NASA in 2013 demonstrates this ability of AM to reduce system complexity. NASA redesigned an engine fuel injector, which previously was composed of 115 individual subcomponents, to contain just two subcomponents. The redesigned injector was able to fuel an engine that produced 20,000 pounds of thrust (10 times more than any injector previously produced using AM) in environments of up to 3,300°C while withstanding 1,400 pounds of pressure per square inch. The success of this initial test has led NASA engineers to believe a combination of increased performance, reduced assembly weight, and lower production costs make AM-produced fuel injectors a viable technology for final production engine and rocket components.[23]

Increased customization, or "variety is infinite"

AM also enhances manufacturers' ability to create individually customized products. The technology is well-suited to product customization because it can support a wide variety of complex geometries without the manufacturer needing to incur the additional set-up costs typically associated with tailoring a product. For example, using conventional manufacturing techniques, customization can require multiple unique machine set-ups, unique molds and other tooling, and product-specific post-processing. AM can produce custom outputs without physically changing the production equipment to avoid many of these requirements.[24]

When manufacturers use AM to produce customized outputs for every unique user, they are using the technology to support mass customization—providing increased value to the customer without a corresponding increase in costs. Mass customization using AM is starting to gain traction in the medical device and the consumer product industries.

As an example, Siemens is currently pairing its new medical scanning technology with AM to mass-manufacture custom hearing aid shells for individual customers.[25] AM allows Siemens to manufacture up to 30 custom hearing aids during each four-hour production run, reducing production lead times and component inventory. Siemens has created over 10 million custom hearing aid shells using AM and claim they provide a better-fitting product that improves customer satisfaction.[26]

Enhanced performance

AM's ability to simultaneously manage complex component geometries, simplify component systems through part reduction, and facilitate customization offers designers the opportunity to build products designed for performance rather than for manufacturability (as required by more traditional manufacturing techniques). Companies in the aerospace industry have embraced AM to enhance performance by building parts that reduce weight and improve fuel economy.[27] Companies in the life sciences industry use AM to improve patient outcomes.[28] Other industries such as automotive and consumer products leverage AM to make stronger components with less waste by products.[29] The ability to make precise physical replication combined with portable 3-D machines has the potential to make or repair spare parts on location without the need for large inventories of parts.

AM technology, product evolution, and the future

AM technology represents a potentially valuable avenue of exploration and investment for companies as they consider evolving their products in response to market demands. As the technology continues to

[23] "NASA and 3D printing: Sky-rocketing," *Economist*, September 3, 2013.
[24] Eyers, D. and Dotchev, K. "Technology Review for Mass Customization Using Rapid Manufacturing," *Assembly Automation* 30, no. 1 2010.
[25] Parsi, S. and Barry, S. "Simultaneous Negative Cast and Shell Fabrication for Custom Hearing Aids." US patent US20100026775 A1, filed July 31, 2008, and issued February 4, 2010.
[26] Froelich,M. *Insio: A new standard in custom instruments*, Siemens, 2013.
[27] Coykendall, J, et al. *3D opportunity in aerospace and defense: Additive manufacturing takes flight*, Deloitte University Press, June 2014.
[28] Snyder, G., et al. *3D opportunity in medical technology: Additive manufacturing comes to life*, Deloitte University Press, April 2014.
[29] Giffi, C., et al. *3D opportunity for the automotive industry: Additive manufacturing hits the road*, Deloitte University Press, May 2014.

improve, its ability to enhance product performance is expected to continue to increase. As performance increases, AM use is likely to continue to migrate from being an advanced technology used only by innovators to a more commonly used technology for core production activities.

Some challenges against more widespread use of AM for product enhancement remain:

- Manufacturers require both a broader selection of printable materials as well as better material performance;
- AM must become more cost-competitive with traditional manufacturing techniques;
- Product designers must become familiar with the technology and the design principles that are best suited to AM's unique capabilities.

These challenges are by no means show-stoppers; given the current pace of innovation, improvements in speed and performance, as well as lower costs and new advanced materials will likely accelerate the spread of AM, widening the lens of customized products that can be produced quickly to order with minimal wasted effort in design or production.

Smarter: Internet of things

Information technology coupled with sensor technology is revolutionizing products, making them both "smart" and connected. The "Internet of Things" (IoT) refers to the growing number of smart products which combine traditional hardware with software, sensors, data and analytics, connectivity, miniaturization of devices, and computer processing power.[30] In essence, technology is becoming an essential element of products, and products themselves are becoming more networked and more able to connect with one another.

According to Senate Commerce Committee Chairman John Thune, IoT "may be the most important trend in technology right now."[31] While IoT is a hot topic amongst legislators, technologists, and industry insiders[32], many end users may not be familiar with the vernacular, though most are currently engaging with IoT in their everyday lives, perhaps without even realizing it. Wearables technology (i.e., Nike Fuelband, Fitbit, Jawbone) represent a popular use of IoT technology to collect, monitor, and share health data. Health monitoring for individuals using IoT devices and implants is already impact the patient experience and healthcare systems, alerting doctors and individuals that medical events are imminent prior to a crisis. Residential utility and security systems that can be remotely operated from a smartphone or tablet device, as well as appliances (including thermostats) that can be programmed to conserve energy by adjusting themselves to external conditions and/or peak periods throughout the day both represent forays into IoT for everyday home use.

As smart products become a more ubiquitous feature in our daily lives, the implications for advanced manufacturing are significant – not only because devices that were previously produced using traditional or current advanced methods will need to be re-designed to come online, but because IoT can evolve the advanced manufacturing process itself across the value chain.

Emerging applications of IoT for advanced manufacturing

While still in its early stages of adoption, the applications for IoT in advanced manufacturing have accelerated at an exponential pace, including the following examples:

- **Preventative and predictive maintenance:** Ranging from pumps and valves to HVAC to medical systems to aircraft engines, the use of sensors and ubiquitous connectivity is improving product reliability and saving owners the hardship of unplanned maintenance and costly service expenditures. We are no longer waiting for a break in order to fix a product.
- **Smart grids for infrastructure**: Utilities are already establishing smart grids to monitor energy usage patterns, spikes, and performance. Adjustments can not only be made in real-time, but engineers and

[30] *Disruptive Technologies: Advances That Will Transform Life, Business and the Global Economy*. McKinsey Global Institute, 2013.
[31] Quote from John Thune, courtesy of The New England Council.
[32] *Top Ten Strategic Technology Trends for 2015*. Gartner Research, 2015.

analysts can use the data generated to gain a "bird's eye view" of usage and consumption patterns, and use that intelligence to smooth demand and encourage or incentivize conservation.

- **Material flow and product distribution:** Using RFID and sensors, material flow can be now tracked from raw materials to the factory to warehouses to transportation and eventually to the customer himself, giving detailed insight into all aspects of the product supply chain.
- **Remote monitoring**: With IoT, data collectors and data access have expanded greatly for control engineers. By enabling the collection of complex data sets from a multitude of embedded devices, a manufacturing system becomes more fundamentally interconnected. Control engineers can now collect big data and use analytics to identify trends, and predict future outcomes within the manufacturing process, in addition to responding in real time.
- **Thinking machines:** Machines with embedded actuators and sensors can be programmed to take more human-like actions, allowing robots to go into situations and locations that are too dangerous for humans.

Implications of IoT for the advanced manufacturing ecosystem

The Internet of Things is more than just connections between machines – it is about the ability to have cheap and tiny sensors that collect information, share that information with other machines and turn information into action. Previously, manufacturers would create a product, ship it, and unless something went terribly wrong, would never hear from that product again. Those days are over – with smart, connected products and the IoT, manufacturers have the ability to track, manage, and control the product even after it leaves the warehouse or the store shelf. This new level of insight and control accelerates innovation and gives rise to new value opportunities resulting from integrated services throughout the product's life cycle.

The rapid evolution from a traditional products economy to an IoT world brings challenges for even high-performing advanced manufacturers. Smart, connected products will require companies to construct an entirely new technology enterprise to design, build, and connect products to cloud technology, while integrating multiple legacy systems with the next-generation software platforms required to bring the product online and permit it to "talk" with other systems. In addition to revamping the process to create IoT-enabled products, manufacturers will additionally have to acquire substantial analytical capabilities to make sense of the enormous data that will be generated from smart products. According to Jim Heppelman, CEO of PTC (see inset), "IoT is streaming in information - you hear the voice of the product, but the product speaks Greek, and it speaks quickly. If you can't understand what it's telling you, then it's just noise." IoT creates a necessity for software designers, programmers, and integrators, as well as data scientists and data analysts to interpret the information created from connected products and turn that information into something actionable and of value. These critical success factors in the IoT economy demand a markedly different set of skills and capabilities than most advanced manufacturing possesses today. Heppelman is quick to quote, "Like it's been said, you go to sleep in an industrial company and you wake up as a software company."[33] Fortunately, in New England there already exists significant talent – in information technology, product design technology, sensors and big data – to seize this competitive advantage.

[33] Interview with Jim Heppelman, President and CEO of PTC, February 2015.

PTC®

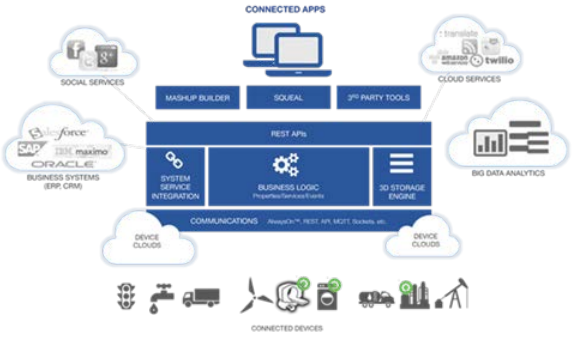
From sensing to making sense: PTC's Internet of Things

Founded in 1985, PTC has evolved from its beginnings as a leader in computer-aided design (CAD) to assume the role of an IoT Sherpa, guiding advanced manufacturers through the landscape of integrating smarter, connected products with technology platforms. Headquartered in Needham, MA, PTC develops and delivers technology solutions used primarily by manufacturers to design, operate and maintain complex products. In addition, PTC's technology is also used to connect products to the Internet for purposes of capturing and analyzing information from them.

PTC is a primary example of how game-changing IoT technology is revolutionizing services delivery and advanced manufacturing as an industry overall. The requirements of IoT now demand an expanded set of capabilities that bear closer resemblance to Silicon Valley than to a shop floor. In the words of CEO Jim Heppelman, "If toasters are connected to the cloud, you need both cloud creators and toaster makers, and someone to integrate the two with software." To advance its offerings to support IoT adoption, in 2013 PTC acquired ThingWorx, and in 2014, Axeda, two leading software platforms for integrating products with cloud technology and the IoT.

PTC's ThingWorx platform allows companies to leverage the power of IoT by building and running applications that transform data into insights which can drive innovation. Through acquisition of the ThingWorx platform, PTC now "offers its customers a means to establish a secure, reliable connection to their products as well as a platform to rapidly develop applications for maintaining and operating them."[34]

PTC®



But how does the leadership of a manufacturing company learn how to integrate IoT when the technology exists beyond the recent scope of advanced manufacturing? One area of shared value PTC offers to enable manufacturers to adopt IoT more quickly is to provision freeware demonstration "sandboxes" for any interested party through their PTC.com website. By allowing individuals to practice IoT applications using ThingWorx, PTC enables them to self-instruct as well as view the user friendliness and versatility of the tool. According to Heppelman, "the best forms of corporate responsibility are the ones that help the community as well as the business." By teaching manufacturers to teach themselves about the Internet of Things, PTC is helping advanced manufacturing move into a new, connected era.

The Internet of Things will be game-changing for consumers and manufacturers alike. The number of devices connected to the Internet currently exceeds the total number of humans on the planet, and we are accelerating to as many as 50 billion connected devices by the end of the decade. IoT thus has the potential to unleash as much as $6.2 trillion in new global economic value by 2025[35]. By enabling computers and mobile devices to receive data from any physical object, IoT will make possible the monitoring, control and optimization of equipment; and with that capability, IoT could yield products which are truly autonomous, reducing the need for human operators. Essentially, IoT will expand the boundaries of current industries, if not disrupt them altogether. As noted in a recent *Harvard Business Review* article, "Smart, connected products will give rise to the next era of IT-driven productivity growth at a time when the impact of earlier waves of IT has largely played itself out."[36]

[34] From "IoT impact on manufacturing" website, http://www.ptc.com.
[35] "Internet of Things." Blog post. Boston Commons High Tech Network, October 2014. http://bostoncommons.net/internet-of-things/.
[36] "How Smart Connected Products are Transforming Competition", *Harvard Business Review*, November 2014.

Game changers: does fortune favor New England?

Louis Pasteur is quoted as saying “fortune favors the prepared mind.” As demonstrated in the previous chapter on New England’s competitive advantages, the region possesses several concentrated industry clusters that aggregate the activity of firms and their suppliers of all sizes, nurturing knowledge exchange and efficiency gains through proximity and network relationships. Added to these industry specializations are a set of strong cluster capabilities that are industry-agnostic and position the region favorably to adapt to the possibilities that game-changing technologies represent. Coupled with a leading research infrastructure that supports numerous start-up incubators and centers of innovation, New England has the aptitude to embrace future waves of technological advancement and incorporate them into the regional economy.

But IoT, along with the other game changers mentioned above, are disruptive forces that will fundamentally alter the requirements faced by advanced manufacturers in terms of the equipment, technology, workforce, skills, and capabilities required to assemble, integrate, and operate the now-empowered machines to connect to each other and to the cloud, and to make sense of the voluminous “noise” of data that is collected from them. These requirements are a significant departure from those of the past decade, and leading schools of thought indicate that the pace of acceleration will only continue to increase. Moving forward, the question we must now ask of ourselves is “Are we truly prepared? And if not, what must New England do now to prime itself for advanced manufacturing’s next wave of opportunity?”

How We Get There: Seizing the opportunity

Building on a rich tradition of "Yankee ingenuity," advanced manufacturing in New England has successfully harnessed the power of innovation to increase productivity and speed the region's recovery from the recent economic downturn. The future appears prosperous; however, the enabling environment that supports the advanced manufacturing industry is currently challenged to meet both current and future demands for talent, infrastructure, and technical assistance driven by the industry's rapid advancement. Given the game-changing technologies outlined in the previous section, one must question whether we are even fully aware of the additional needs that these disruptive technologies will introduce.

Workforce development, economic development, ecosystem and infrastructure challenges threaten to dampen the trajectory of growth of advanced manufacturing, along with the auxiliary jobs throughout the economy that supply, transport, sell, maintain and consume the industry's output. The diagram below demonstrates how the virtuous cycle of industry growth in New England's advanced manufacturing cluster, supported by network strength, capability clusters, and highly sophisticated talent, is weakened by a dampening cycle of factors that are systemwide and national in scope. These negative influences erode the vitality of the region's skills, network, and productivity:

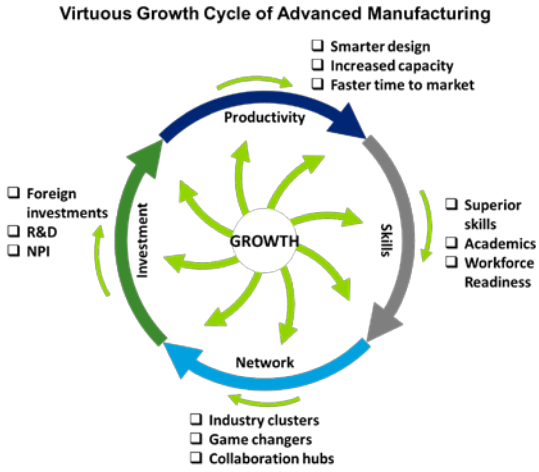


Figure 26: Growth Cycle of Advanced Manufacturing

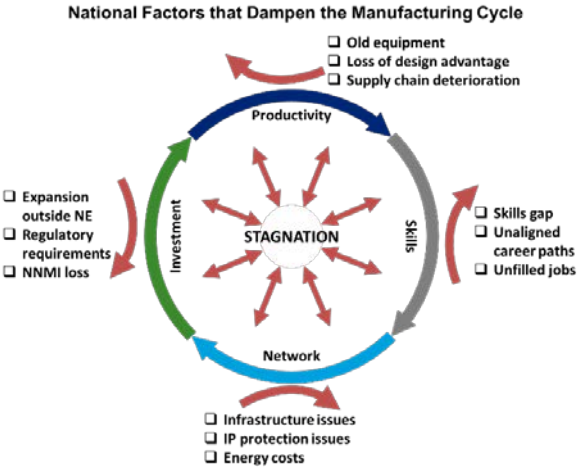


Figure 27: National Factors that Dampen the Manufacturing Cycle

While the dampening factors above are not unique to New England, to disregard or underestimate the industry's growing pains and their regional context is to leave an immense opportunity on the table. Deloitte and The New England Council conducted a series of interviews and working group sessions with industry, educational and state/local/regional government stakeholders across the region during the course of this project. Some overarching themes emerged from these dialogues:

1. There is a compelling opportunity available to cultivate a leading advanced manufacturing cluster in New England, one that will sustain future generations both economically and technologically;
2. New England will not fully realize this opportunity on its current path, a path that threatens to keep high-paying jobs vacant, and depress productivity over time, deteriorating the region's network strengths from advantaged to just average;
3. Many "islands of excellence" exist across the current ecosystem, led by a small cadre of organizations who are leading the charge to address the industry's complex issues. In many cases these efforts are driven by economic necessity, but lack the resources to coordinate, replicate and scale on a state or region-wide level;
4. A coordinated effort across a broad range of stakeholders – industry, government, educational institutions, and others – is necessary to take full advantage of the opportunity to grow;
5. This coordinated approach has been demonstrated in other regions across the country and it can work for New England.

The observations above introduce a fifth "A" into the "A's" of advanced manufacturing, which stands for the ***acute*** nature of the challenges to growth faced by the industry. The window of opportunity that exists today to preserve New England's advantaged manufacturing sectors is not a guarantee for continued growth in the future, should the factors that contribute to the dampening cycle of industry growth continue unchecked. This report is a call to action to develop an integrated plan across the region, one that addresses challenges in a manner that will act as a force multiplier – delivering value for stakeholders far greater than they could achieve alone. That plan should focus on five key challenges, discussed in detail below.

Challenge: Education and the much-discussed "skills gap"

Almost every conversation – whether with educators, industry leaders, public agencies or researchers involved in manufacturing – centered on the "skills gap." This gap was described as consisting of both workforce development (sourcing the talent to fill a growing number of vacant manufacturing positions) as well as workforce training (upgrading the skills of qualified workers to meet the needs of advanced manufacturing employers). Given the challenges articulated by those interviewed, this issue is hardly unique to New England; but, it stands to reason that the first regional cluster to successfully develop replicable and scalable solutions to address the skills gap will likely be the one best positioned to capitalize on growth opportunities within the industry.

From a labor supply perspective, the looming mass retirement of Baby Boomers from what is already an aging industry (with an average employee age of 56)[37] leaves little room for firms to maneuver. Postponing retirement for incumbent workers represents but a superficial, short-term solution. To compound matters, as more baby-boomers retire from the industry, there appears to be scant interest from generations now entering the workforce to pursue a career in a field that is still perceived by many as dark, dirty, dangerous, and declining.

From a workforce skills perspective, the capabilities needed in advanced manufacturing plants have evolved to keep pace with commercial innovation, creating a need for employees who are more critical thinker, problem solver and team player than rote machine operator. That said, K-12 education, technical training and higher education curricula have not evolved sufficiently to deliver the workforce to meet this new demand. In addition to lacking core STEM competencies such as measurement and arithmetic required to perform their job, many candidates also lack "essential skills" in teamwork, problem-solving, and communication to be considered workforce-ready. As Dennis Dio Parker, an Assistant Manager at Toyota, so eloquently put it in the radio documentary *Ready to Work: Reviving Vocational Ed*, "…high schools and colleges in the US are failing to turn out graduates with the mix of technical expertise, problem-solving ability and communication skills that [we] need. They're not talented at the level we need them to be talented."[38]

[37] Ayres, S. and Schwartz, B. "The Bottom Line: Apprenticeships are Good for Business." Center for American Progress, 2014.
[38] Hanford, E. "A Company Short on Skilled Workers Creates its Own College Degree Program," An essay from the radio documentary *Ready to Work: Reviving Vocational Ed.*, American Radioworks, September 2014.

The combination of the above factors present a stark reality where a significant number of highly compensated, skilled jobs are remaining vacant for extended periods of time – and the gap only threatens to widen in the coming years. According to a recent study by Deloitte and the Manufacturing Institute,[xix] 84% of executives agree that there is a talent shortage in US manufacturing and this statistic is evidenced by the same study's report that six out of ten open skilled production positions are unfilled due to talent shortage.[39] Extrapolated to New England, the skills gap measures approximately 105,002 workers across the region over the next ten years.[xx] Given the average 90+ days to fill vacancies with a qualified worker, plus the investment advanced manufacturers must make to source and train recruits to reach a productivity threshold, over time the indirect costs of vacant positions impacts both Human Resources departments and the bottom line of advanced manufacturers.

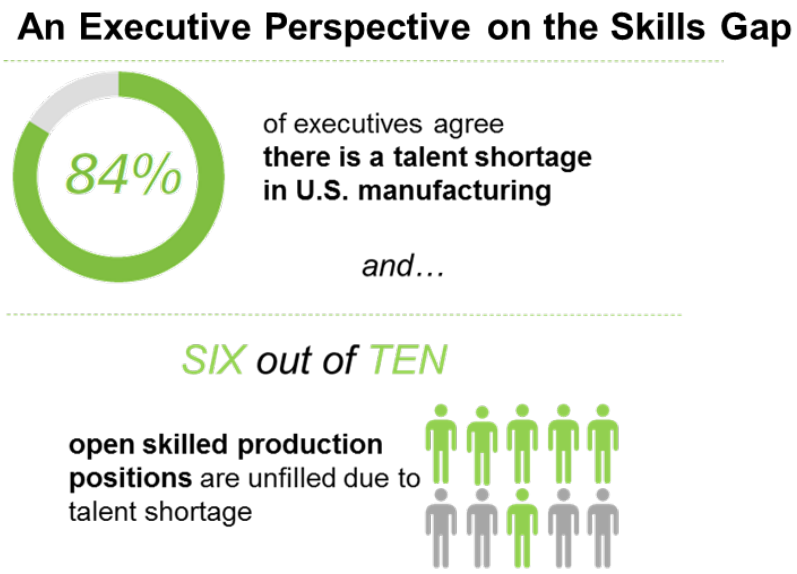


Figure 28: An Executive Perspective on the Skills Gap
Source: Deloitte and the Manufacturing Institute, 2015

The potential impacts of a skills gap to the New England advanced manufacturing cluster are significant, accompanied by a sizeable multiplier effect for the regional economy beyond manufacturers themselves. For every advanced manufacturing position that remains vacant, another 2.5 jobs are sacrificed within the supporting commercial ecosystem of suppliers, logistics providers, sales, and maintenance / repair / overhaul (MRO) firms that rely advanced manufacturing to support their growth[40]. The macroeconomic effects stretch further still, to the consumer economy where a shortage of skills and workers in production translates to a possible reduction in overall consumption. The ripple effects of a skills gap in advanced manufacturing stretch into the far reaches of our economy. Although there is broad consensus that "something" needs to be done, just what this "something" is remains open for debate.

So if these critical workers aren't currently available and if the educational system we have now is not equipping the next generation with the skills they need, where will these workers come from?

Opportunity: Partnerships and the new apprenticeship model

For advanced manufacturing, traditional educational instruction represents only a fraction of how professionals acquire the skills needed in the workplace – a large component of modern manufacturing capabilities are developed through hands-on experience, using specific machining tools and software, and through coaching from more experienced practitioners. Michael Tamasi, President and CEO of

[39] *The Skills Gap in Advanced Manufacturing: 2015 and Beyond*. Manufacturing Institute and Deloitte Consulting LLP, February 2015.

[40] Dollar, B., et al. "Help Wanted—Addressing the Skills Gap in US Manufacturing." Advanced Manufacturing Institute and Deloitte Consulting LLP presentation, 2015.

AccuRounds in Avon, MA, echoes this sentiment: "You can't train somebody up to be a seasoned manufacturer at school; what's needed is a training and apprenticeship program."[41] Apprenticeship experiences that expose trainees to the application of skills they have learned in the classroom serve to both close the skills gap while creating an effective means of skill transfer from incumbent workers to successive generations, a mentorship model that also has the potential to build employee engagement and long-term commitment to a career in the industry.

Traditional staff development models subscribed to an "all in" approach, whereby a single employer would nurture the development of the employee from entry level through specialized instruction, possibly also supplementing their on-the-job learning with customized training or technical instruction at a local community college or university. However, in our discussions with industry, we repeatedly heard that smaller companies do not have the resources – in dollars and in time – to support employees with skills gaps, and that firms both large and small are hesitant to invest wholesale in a highly mobile employee who may separate from the job, taking the skills investment with them to a competitor in the marketplace.

> While it is no longer reasonable to assume a lifelong career at a single employer, so too is it no longer practical to assume that one employer will shoulder the investment of training what has become a highly mobile and flexible workforce.

As it has become less common for employees to assume a lifelong career with a single employer, it is likewise impractical to assume that one employer would or should shoulder the full cost of training and investing in this highly mobile and flexible workforce. To address the skills gap and cultivate the advanced manufacturing leaders for the future, clusters of companies with a shared interest in the skills being developed will need to collaborate to develop this next generation workforce, and adopt a willingness to invest in the cross-pollination of talent throughout the region, not just in their immediate backyard.

Partnerships that pool resources at an industry level, possibly with governmental or academic support represent a way to overcome risk and resource constraints with respect to human capital in the advanced manufacturing space. Value-adding partnerships leverage the core strengths of each stakeholder (i.e., advanced manufacturers provide industry requirements and employment opportunities, educators provide training and placement assistance and government provides flexible workforce development funding) to allow each party to contribute to the overall skills development model, while each focuses on doing what they do best.

Successful cross-sector partnerships take a variety of forms, for example:

- **Industry-Designed Educational Partnership Program**: Vermont HITEC educational programs are employer-partner sponsored, open only to the employees and invited guests of those partners, and oriented solely for the purpose of recruiting potential employees and current employees of those partners. Vermont HITEC educational programs are designed to provide the academic knowledge, technical skills, and hands-on training needed to succeed in a specific career field. At the same time, a Vermont HITEC education helps individuals develop the communications, teaming, leadership and analytical skills essential for career growth and advancement. The program's year-round, on-demand format enables participants to complete their studies and advance in their employment quickly.

[41] Interview with Michael Tamasi, President and CEO of AccuRounds, January 2015.

- **Industry Engagement for Curriculum Development, Delivery and Feedback**: Higher education, particularly community college districts, have demonstrated an eagerness for industry input around which to design their curriculum. At Keene State (a four-year liberal arts college in New Hampshire), the administration has taken private sector collaboration seriously – from bringing in business leaders to speak to students on industry once per week to custom designing curriculum. Rather than relying on one major company to set the curriculum, Keene State works closely with many companies to develop a curriculum that is broadly appealing.[xxi] Not only is this approach supporting the small and medium-sized companies in New Hampshire, but it is also attracting new manufacturers to the region.

- **Industry Collaboration to Standardize Curriculum for Advanced Manufacturing**: The Connecticut College of Technology (CCOT) represents a systemwide initiative between the state's community colleges, as well public and private universities and technical high schools (as well as some individual non-technical high schools) to develop a statewide recognized credentialing system that accrues stackable credits that can lead to an Associate's degree or a four-year undergraduate degree. Courses in over 17 technical certificate programs are crafted specifically from industry input, usually gathered through partnerships with statewide or regional manufacturing associations. According to Karen Wosczyna-Birch, Executive Director of the Regional Center for Next Generation Manufacturing at Connecticut Community Colleges, working with industry employers gives them some "skin in the game," and likewise orients the program to award credits based on skills and capabilities, rather than "seat time" in a classroom[42]. Given the statewide scope of the program, CCOT not only provides students access to flexible education options with multiple on-ramps and off-ramps, but the credentials they acquire are recognized statewide by the manufacturers who designed them, providing them with greater flexibility and confidence as they launch their careers.

[42] Interview with Karen Wosczyna-Birch, February 2014.

Adding manufacturers, educators, and entrepreneurs into the mix: CCAT's cross-sector partnerships

With a mission to address economic challenges by creating partnerships which collaboratively provide services and resources to industry, academia, government and non-profit organizations, **The Connecticut Center for Advanced Technology (CCAT)** in East Hartford, CT is an economic development organization that connects stakeholders in the high tech manufacturing industry. They help them implement innovative solutions, increase efficiencies and improve workforce development.

CCAT offers the space, tools, and expertise to support small businesses, entrepreneurs and students to help them with the opportunities available in advanced manufacturing. The Advanced Manufacturing Center (AMC) at CCAT offers expertise, applied research and development work using metals and plastics in additive manufacturing (3D printing) for prototype fabrication, repair, modification, and cladding of parts with integrated features and properties that are difficult to make using traditional methods. As a result of the work being done at AMC, the initiative was named an official Center of Excellence for additive manufacturing services by Optomec, Inc., a world-leading manufacturer of laser powder-directed energy deposition systems.

In June of 2014 CCAT[43] received a two year contract award with America Makes, the flagship of the National Network for Manufacturing Innovation, to advance the use of aerospace alloys in additive manufacturing. America Makes strives to foster collaborative projects in a pre-competitive environment, to further implementation of advanced additive manufacturing concepts and technology. It also endeavors to develop industry workforce skills necessary to support additive manufacturing in the U.S. This project brings together research institutions at two different universities, leading manufacturing corporations and institutes.

Additive manufacturing is but one of several advanced manufacturing initiatives sponsored by CCAT. The template that this organization uses to assemble cross-sector stakeholders to promote and reinforce innovation in a disruptive technology may represent a viable model to replicate and/or scale in other areas of the New England region. CCAT is working in partnership with the Connecticut Department of Economic and Community Development and the State of Connecticut on the "Regional Aerospace & Defense Exchange" (RADE), a Department of Defense Office of Economic Adjustment DIA initiative. RADE focuses on strengthening ties across the New England region to address projected spending changes, affect policy change, share best practices, and plan diversification strategies for the A&D industry. The project has brought together various parties to facilitate sharing information and leading practices across New England.

One arena where cross-sector partnerships are particularly fruitful is in the development of apprenticeship programs. Through collaboration by government, education and industry, such programs can provide the hands-on instruction critical to success, while facilitating placement of candidates, mitigating the risk of employing an individual who is still learning, and creating a career pipeline for promising talent. In fact, apprenticeship, temp-to-hire and paid internship models all represent ways for manufacturing firms to source and vet talent, in a manner that is often more effective than the "post and pray" approach of online recruitment[44].

- **Cross-Sector Partnerships to Provide Apprenticeship Opportunities:** In Rhode Island, the Governor's Workforce Board uses General Revenue funding to support the cost of an industry apprenticeship placement facilitated by the Polaris Manufacturing Extension Partnership and industry employers. The Work Immersion Program, in which employers are partially reimbursed (up to 50%) for wages paid to college students or recent college graduates, increases the rate of reimbursement for employees that are later hired in a full-time capacity. This program provides practical learning opportunities, contributes to the employability of students, and bridges the perceived skills gap between employers and students through preparing and training potential future employees. Rhode Island subsidizes the risk that companies take when providing internships on the hope that spending

[43] Press Release, "CCAT Announces $163K America Makes Contract for Additive Manufacturing Innovation." Metro Hartford Alliance, June 25, 2014.

[44] Interview with Brian Howard, Deb Gaynor, Courtney Murphy, Howard Jenkins, Paul Marsiglio and Donna Elks, Electric Boat, February 2015.

money and time on students to gain skills will eventually be repaid through converting the students into productive employees.

- **Cross-Sector Partnerships to Combine Certification with On-the-Job Training:** Thornton Academy in Southern Maine has partnered with the National Tooling and Machining Association (NTMA) to provide high school students the opportunity to earn a competency certificate in Precision Manufacturing, and has created a job shadow/internship program with area manufacturers to apply classroom learning in a hands-on setting. The ability to earn a certificate, along with the opportunity to participate in the internship program allows students to gain practical experience and positions them well for multiple career trajectories, should they choose to enter the workforce directly after high school or pursue further education.

Closing the skills gap will require manufacturers to "double down" on strategic sourcing of underutilized talent, upskilling the "80% candidate" who may possess some but not all of the required skill sets, and doing so with recognition that mobility is to be expected, and that employee migration does not have to be detrimental to the business. Participation in cross-sector partnership models that inform educators on the skills needed and provide them a feedback loop, establish apprenticeships and paid training, while identifying trainees that can be recruited out of an apprenticeship model for long-term employment with government support, has the potential to enable advanced manufacturers to adapt to the flexible staffing models emerging in today's workplace, while mitigating some of the risk that exists in a competitive industry environment.

Opportunity: "Make it" a better brand

Perceptions of careers in manufacturing are a major factor in the increasing gap between skilled workers and available advanced manufacturing jobs in the United States. In a survey conducted by Deloitte and the Manufacturing Institute, 18-24 year olds rank manufacturing dead last among industries in which they would choose to start a career.[45] And while STEM has been capturing the attention of educators, according to a recent study by Georgetown University's Center on Education and the Workforce, more than 30% of engineering, computer science, and mathematics majors choose careers in business or professional services rather than in science and engineering.[46] In our discussions with educators in New England we heard repeatedly that children are losing interest in manufacturing as a career long before they enter high school and that education about advanced manufacturing needs to be expanded to include the guidance counselors, the teachers, and the parents – all those who advise students as they think about their passions and their future.

Children are losing interest in manufacturing as a career long before they enter high school…education about advanced manufacturing needs to be expanded to include the guidance counsellors, the teachers, and the parents – all those who advise students as they think about their passions and their future.

While there are many initiatives focusing on addressing student awareness and perception of advanced manufacturing, a few New England examples that apply holistic approach are:

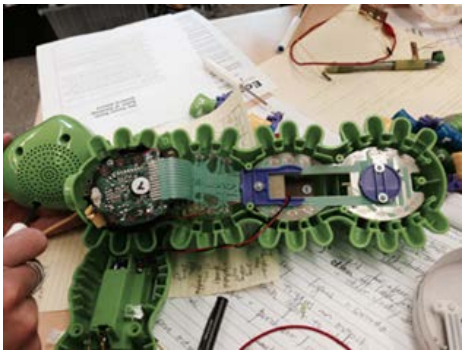
[45] *Unwavering Commitment: The Public's View of the Manufacturing Industry Today*. Deloitte and The Manufacturing Institute, 2011.
[46] Carnevale, A., et al. *What's it Worth: The Economic Value of College Majors*. Georgetown University Center on Education and the Workforce, May 2011.

- The **MassDevelopment "AMP It Up!" program** is a highly successful Massachusetts awareness initiative focused on helping students (middle through high school) and adults (parents, guidance counselors, and other influencers) to take advantage of the many highly skilled, well-paying manufacturing jobs available. Through AMP It Up!, students who like to build things and solve problems can plan for a lucrative career with a choice of jobs. The program also provides schools with resources and guidance regarding jobs in advanced manufacturing, factory automation, product development, nanotechnology, direct digital fabrication, micromanufacturing, and other exciting fields.
- **Connecticut. Dream It. Do It.** through the Connecticut Center for Advanced Technology (CCAT) is focuses on bringing students, families, educators and manufacturers together to gain a better understanding of advanced manufacturing – what careers are possible, what working in advanced manufacturing truly means, and what the rewards can be. The program aspires to live their motto: "You dream it. We'll show you how to learn it and do it."
- The **PBL Projects of the New England Board of Higher Education** (NEBHE) are a series of STEM-themed, problem-based learning curriculum and professional development projects funded by the National Science Foundation's Advanced Technological Education program (NSF ATE). Each of the PBL Projects has developed a collection of authentic real world multimedia case studies called "Challenges" with industry partners in the areas of optics and photonics, sustainable technologies, and advanced manufacturing (in process).[47] Problem-based learning not only shifts the lens from rote learning to the development of competencies such as problem-solving, critical thinking and teamwork that will serve students in their professional and personal lives, but the Challenge applications to advanced manufacturing spark students' enthusiasm for STEM learning and industry challenges in a way that subtly shifts their perceptions of the industry as a place where "cool" assignments reside.

Both of the aforementioned programs connect students, families, educators and companies to expose them to each other, as well as to assist the community to gain awareness of the opportunities, the environment, and the potential career trajectories associated with a future in advanced manufacturing.

Throughout the interviews conducted for this report, a common theme was a perceived need to "re-brand" advanced manufacturing, using vernacular and terminology that would appeal to a Millennial workforce, as well as gain positive reception from their parents and support networks. The cultural rise of the "Maker Movement," which focuses on the design, creation, and production of products in an entrepreneurial settings by "crafters, hackers, and tinkerers,"[48] may be a viable way to re-frame the manufacturing skill set in a manner that retains the core learning fundamentals required to succeed in the advanced manufacturing field, but set in a context that is appealing to the next generation workforce. These renegade and maverick archetypes of the 21st Century appeal to the workers of tomorrow, and latching on to the momentum of this semi-subversive movement in design and entrepreneurialism could represent a guerilla approach to grabbing the attention of a heretofore indifferent audience.

[47] NEBHE PBL Projects website, http://www.pblprojects.org/.
[48] Hatch, M. *The Maker Movement Manifesto*. McGraw-Hill, 2014.



The noisiest room in school: Libraries become "maker spaces"

Another group that is adding its collective power to the "make it" revolution is the school and community librarian. Ironically, librarians have embraced the maker movement, inviting in the noise and excitement that equipment like 3-D printers bring. No "SHHH!" allowed in this place of learning!

Since the early part of the decade, "maker spaces" have become a buzzword around libraries. In 2012, an IMLS grant-funded program "Make it @ Your Library" further institutionalized this relationship by bringing into one place resources that librarians can access to promote use of advanced manufacturing materials in libraries. As a result, students are flocking to the library to design, make, build, and create.

Vermont librarians have worked in recent months to bring the maker ethos to libraries across the state. In the summer of 2014, the pilot program *Vermont Librarians and Makers Spark a Culture of Innovation* produced 28 programs across the state. As part of this initiative, over 500 hacker kits were distributed to kids, parents, K-12 teachers, and librarians. The participating libraries are now independently offering the programs that are led by their own librarians.[49]

Likewise, at the Westport Library in Connecticut, there has been a MakerSpace for three years that was built with support from the Institute of Museum and Library Services. As the library so eloquently points out, "Libraries have always adapted to meet the needs of the people they serve. The Westport Library has been evolving into a community hub for many different kinds of learning experiences, and some time ago the concept of providing space for creation and production took hold…The development of the MakerSpace is a natural continuation of a clear interest in the Maker Movement. The MakerSpace is where people can create content as well as also consume it--an incubator for ideas and entrepreneurship.[50]

Photo Credit: Vermont Engineering Initiative

The recent rise in popularity of the "Maker Movement" presents an opportunity to generate excitement about manufacturing with students. Unfortunately, not all teachers fully understand how to incorporate the academic concepts behind the Maker Movement into their traditional educational curriculum. Examples of relevant subjects that have the potential to incorporate "making" into their curriculum include: math, science, art/design, and business/economics. One possible way to integrate the Maker Movement into educational curriculum is through a series of classes in which students design, make, and ultimately sell a tangible product. This sequence of manufacturing processes mimics those found in industry, and presents students with an opportunity to own their product from concept through creation. The design component of the curriculum requires students to think creatively about their product, and can also be used to introduce students to basic CAD programs, a core component of modern advanced manufacturing. Additionally, the design phase presents an opportunity for students to engage in collaborative feedback sessions with one another to improve their design prior to manufacturing. Similarly, the curriculum's make component could provide an introduction to additive manufacturing practices that are increasingly common in the advanced manufacturing industry. Students could manufacture their products using basic 3-D printers, and again interact with their classmates to review and revise their product design. Finally, the sell portion of the curriculum enables students to bring their products to market, potentially through an online marketplace, all while learning basic business concepts.

[49] "2014 Was a STEAM-y Year for Vermont!" Blog post. Vermont Makers website, 2014. http://vermontmakers.org/awesomesauce/2014-was-a-steam-y-year-for-vermont/.
[50] Maker Space, website. The Westport Library online. http://westportlibrary.org/services/maker-space/.

Figure 29: "Design, Make and Sell" Technologies Available to Students
Source: Deloitte

Getting creative around how advanced manufacturing concepts are presented to young people and their parents will be a critical success factor for the industry's talent attraction objectives. Prior approaches have adopted a "lead a horse to water" approach, but given that the Millennials aren't drinking advanced manufacturing in its current incarnation, it may be time to figure out a different lens through which to market the industry to capture tomorrow's talent pool.

Opportunity: Improve the educational pathways

New England is renowned for its high quality education – three of the Top 10 and five of the Top 20 universities in the country are located in New England. At the high school level, New England is home to five of the top 11 states ranked for having the best high school education[51]. However, this excellence in education is a double-edged sword. As highlighted in the recent study by Mark Melnik in *MassBenchmarks*, a hidden expense of exceptional talent is that "having a well-educated labor force…impacts workers on the lower end of the education and skill scale."[52] In fact, in light of region-wide academic achievement, employers tend to implicitly raise the educational requirements for job openings across the employment spectrum, drying up the main pipeline for talent entering the manufacturing workforce – those graduates of technical high schools, community colleges and state universities.

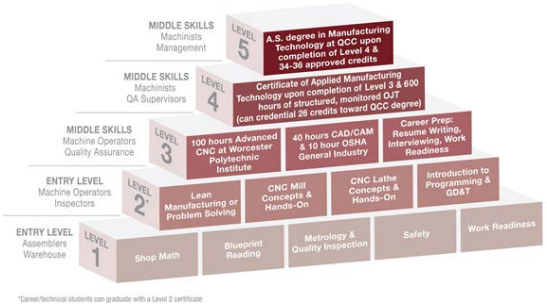
[51] Morse, R. "How the States Compare in the 2014 Best High School Rankings," *U.S. News and World Report*, 2014. http://www.usnews.com/education/best-high-schools/articles/2014/04/21/how-states-compare-in-the-2014-best-high-schools-rankings
[52] Melnik, M. "Educational Requirement Markup and Credential Mismatches in the Greater Boston Labor Market" in *MassBenchmarks*, volume 16, issue 2, University of Massachusetts, December 2014.

As a result of this pressurized academic environment, more and more students are counselled toward universities to attain a four year degree. However, many students are ill-equipped for success at these institutions and frequently drop out, start and stop their education, and are left with large debt and without a degree to show for the time and expense of the effort. One approach to accelerate educational opportunities in advanced manufacturing is to break down the barrier around educational pathways. A tremendous amount of time, resources and energy is lost in the system by students not having the flexibility to apply credits from different educational institutions and from relevant work experience to a recognized certificate or degree. Massachusetts has been leading the way in this area, developing a statewide program, the Manufacturing Advancement Center Workforce Innovation Collaborative, or MACWIC (see inset).

Industry-driven, "stackable" workforce development at the statewide level

The Manufacturing Advancement Center Workforce Innovation Collaborative (MACWIC) is a statewide program in Massachusetts consisting of employer-led workforce training initiatives. Started in February 2012 with an intended purpose to "preserve manufacturing tribal knowledge and to execute the transfer of knowledge and critical skills to the current and future workforce,"[53] the program was born from the realization by Massachusetts manufacturers that they couldn't expand their companies with the current workforce available to them. In order to address these issues, MACWIC partner companies, without government assistance, teamed up with regional education institutions to launch a relevant manufacturing curriculum that would be taught through the collaboration of Workforce Training Providers, Vocational Technical High Schools, Community Colleges, and Universities.

This new MACWIC curriculum ensures that students are learning the practical skills required by Massachusetts manufacturers through an easily accessible tiered curriculum. The first and second tiers of the pyramid are oriented to vocational and technical high school students, and prepare them with basic career readiness skills. Level three of the pyramid consists of a more advanced CNC focus with a goal of producing skilled machine operators. During level four, MACWIC students begin their matriculation into the regional community college system, with 600 hours of on the job training, and the potential to earn 26 credit hours and an advanced entry into Quinsigamond Community College's (QCC) Manufacturing Technology Degree Associate Program. Finally, in level five, students are required to earn 34 credit hours from QCC, to gain their Associates Degree in Manufacturing Technology. This five tiered program is designed to provide students with employable building blocks at each level, and allow for both vertical and horizontal movement, as people may enter and leave the tiered system at different times. Employers now not only have a pipeline for developing their future workforce, but they can also understand the competencies and certificates attained at each MACWIC level.[54]



Since MACWIC's inception, the program's success has led to membership growth from 40 founding members to over 160 member companies today. The 5 tiered-program is now being tested in 15 of the 30 Massachusetts Vocational Technical High Schools, with hopes to expand to others in the near future.[55]

Photo Credit: MACWIC

In addition to MACWIC and CCOT mentioned previously, other New England states are developing recognizable certificate programs and innovative delivery models to entice students to explore advanced

[53] "About MACWIC." Website. http://www.macwic.org/.
[54] "Best Practice: The Manufacturing Advancement Center Workforce Investment Collaborative (MACWIC)." Advanced Manufacturing Regional Partnership Academy (AMRPA) website. https://amrpa.wordpress.com/research/best-practices/macwic/
[55] Interview with Thomas Wesley, Waters Corporation, Head of MACWIC Steering Committee, December 2014.

manufacturing as a career option, while providing substantiation of their credentials to industry employers, increasing the likelihood of a job match and a sustainable outcome of technical education:

- Responding to the shortage of skilled workers in Rhode Island's shipbuilding/marine and advanced manufacturing job market, New England Institute of Technology has leveraged Department of Labor funds in collaboration with General Dynamics/Electric Boat Division, Senesco Marine, RI Carbide Tool, Guill Tool and Engineering, Swissline Precision, RI Marine Trades Association and the RI Manufacturers Association to develop a Shipbuilding/Marine and Advanced Manufacturing Institute (SAMI). The mission of the SAMI program is to provide Rhode Island Employers with a pipeline of skilled Welders and Machinists. SAMI achieves this mission by recruiting, screening, providing career information and hands-on orientation, and training individuals for high-demand careers in these industries all at no cost to eligible SAMI participants or the employers.
- In New Hampshire's Seacoast region, the State of New Hampshire made an investment to develop a center of excellence around composite manufacturing and CNC precision machining. The Advanced Technology & Academic Center at Great Bay Community College in Rochester, in collaboration with manufacturers Albany International and Saffron, developed a custom curriculum for students around composites. Recognizing the need for strong foundational and "soft" skills in any successful workplace, New Hampshire supplements the GBCC curriculum with a tuition-free, 60-hour WorkReadyNH program available to eligible students (the program is also available at all NH community colleges). WRNH helps job-seekers and career builders improve math, reading, information-gathering, communication, team-building and problem-solving skills. The WRNH program's assessment and training services enable students to earn two nationally recognized certificates, while helping employers identify qualified career candidates. Placement for GBCC's graduates is high – in some classes 100% of graduates. This delivery model was recently recognized with a Northeast Economic Developer's Association award for "Project of the Year" and New Hampshire is now looking to replicate this approach for programs focused on defense and aerospace.
- The State of Vermont provides very targeted support to VT Technical College who, working in tandem with the Manufacturing Extension Partnership (MEP), is building a stronger technical two-year program, within which the focus rests on identifying individuals with aspiration and aptitude in order to select the class with the highest probability of success. With costs to train a worker averaging about $10K ($1000 per week in a 10-week program), this program focuses on remedial math and science, as well as industry core terminology and practices. The result of this focus on upskilling strong candidates with remedial skills is a higher retention value and quality for worker. The program has generated significant demand, with 800 applicants for 40 positions in the most recent admissions pool.

As shown in the examples above, our research suggested that successful models of learning pathways are those that: a) capture the minds and imaginations of students before they reach high school, b) provide credit recognition for hands-on and technical learning in additional to classroom instruction, c) integrate cleanly with traditional college prep curriculum at the high school level, d) compensate students competitively and give them exposure to a career in industry, and e) permit students flexibility to pursue multiple career trajectories, be they traditional higher education or full-time work, or a combination thereof. These initiatives, among others, constitute the formation of a lifelong learning pipeline for skills development that addresses the critical skills gap in advanced manufacturing, one that should be scaled up and replicated across the region.

A sense of urgency

The dwindling advanced manufacturing workforce in New England is approaching critical levels of need. History has many examples of bygone industries that were not nimble in the face of disruption, and New England industries are not immune to the debilitating economic effects that a lack of skilled talent will create. A window of opportunity exists to invest in New England's labor pool, but that window is closing fast – the industry stakeholders interviewed estimate that in less than five years, the skills gap will not be recoverable if insufficiently addressed.[56]

[56] Working Session, New England Council Advanced Manufacturing Working Group, March 2015.

While the demand for skilled labor is clear, the approach that New England states take to build out the pipeline of talent for the future may not be so clear-cut. Given that creating a comprehensive solution incorporating the opportunities above could take up to a decade to accomplish, stakeholders must prioritize the opportunities above and develop a plan that will triage the immediate needs of the workforce with young employable adults and incumbent workers, while collaborating across sectors to incrementally (but quickly) build out the programs to attract and train the advanced manufacturers of the future.

Challenge: Addressing the Needs of Small and Medium Manufacturers (SMEs)

Small and medium-sized companies in the manufacturing industry are drivers of innovation and industry-wide growth; however, these firms face a host of unique challenges related to their size within the marketplace. Getting an idea from a prototype to fully operational requires the full resources and focus of the enterprise, and adjusting the product or process along the way often demands more resources than are currently available. SME manufacturers tend to be bandwidth constrained, with staff at all levels wearing many hats.

Investments in innovation required to support advanced manufacturing (such as adoption of new equipment or technology) are often the result of competitive market pressure on SMEs to which they are forced to adapt in order to stay viable, leaving little to no time for strategic initiatives oriented to growth, business transformation, and upskilling the workforce[57]. However, without these types of ancillary business investment, SMEs cannot readily scale to meet the needs of the larger firms that they serve, precluding themselves from additional opportunities and exerting downward pressure on the aggregate growth of the industry regionally.

While policy responses such as the creation of NIST Hollings Manufacturing Extension Partnership (MEP) affiliated centers in each New England state have provided much needed equipment and training resources to ease some of the pressure on SMEs[xxii], correcting market failures that block their access to capital, speed their commercialization of technology, and support tech transfers is essential. Promoting support to scale for the SME community allows these companies to innovate and grow in a manner that mirrors their larger counterparts, and stabilizes the supply chain while supporting continued growth and diversification in advanced manufacturing.

Opportunity: Support to Scale

Small and medium-sized (SME) manufacturers' requirements for growth and the prevalence of opportunities available to them in the marketplace often outpace their revenue stream and their organizational capacity to react. Due to their smaller scale, these companies suffer barriers to growth more acutely than larger firms, and the consequences of their inability to scale span across the larger manufacturing industry, where OEMs and anchor employers rely on them as part of their supply chain.

Policy programs that leverage commercial and public resources to address the growing pains of SMEs represent a larger investment in the advanced manufacturing industry. By helping SMEs to grow, scale and innovate products and methods, such programs can open the door to SMEs for competitive bidding on more and larger contracts, enhance their ability to effectively serve the OEM and Tier One manufacturers, and in turn allow those larger firms to take on more work when opportunities arise. Some examples of these programs include:

[57] Darbanhosseiniamirkhiz, M. and Wan Ismail, W. K. "Advanced Manufacturing Technology Adoption in SMEs: an Integrative Model." *Journal of Technology Management and Innovation*. Volume 7, Issue 4. 2012.

- **Access to Applied Research**: In a recent article published by the American Society of Mechanical Engineers (ASME), an important factor in the German manufacturing success was shown to be the Fraunhofer-Gesellschaft, an independent NGO that provides high-quality, short-term, affordable applied research that SMEs could not otherwise afford. This is not a small organization, but rather a $2.45 billion enterprise that operates more than 60 research institutes with more than 250 business focus areas and core competencies. While it is an NGO, it is supported largely through publicly funded contract research and through many of the publicly-funded educational institutions.[58]

- **Grants to Match SMEs With Innovation Resources**: In Massachusetts, the state's finance and development agency MassDevelopment has launched the Manufacturing Innovation Grants program to connect SMEs with (less than 100 employees) to one of four innovation centers chosen for their technical expertise and capabilities working with advanced manufacturers. MassDevelopment pays the lesser of 75% or $75,000 of the cost of a contract between the SME and the innovation center, and the companies receiving the grant contract directly with Algonquin Industries, Inc., Boston Engineering Corporation, Connecticut Center for Advanced Technology (CCAT), or Worcester Polytechnic Institute (WPI). This program supports SMEs in need of expertise and equipment to support product development, prototyping, scaling up, cost reduction, and other services.

- **Innovation Matching Grants**: In Connecticut, the state-sponsored Manufacturing Innovation Fund has implemented a "voucher" program for SMEs (less than 300 employees), which designates matching grants for innovation work within the organization (up to $50,000) that can be used flexibly to acquire equipment, invest in training, or hire professional services to support business transformation efforts.

- **Seed Grants to Support Tech Commercialization**: In Maine, the Maine Technology Institute provides state-funded seed grants to early stage companies conducting research and development activities. While most textile companies in New England have closed, Tex Tech, a Portland, ME-based company has instead evolved to serve its new markets. Over the past five years, MTI funding has helped Tex Tech accelerate their product development and translate their advanced textiles to high-value markets including ballistic protection, and fire resistant materials. The company has received seven research and development grants from MTI totaling more than $67,000. In turn, the seed funds have attracted more grant funding. For example, one of the $10,000 MTI awards Tex Tech received led to $750,000 in Small Business Innovation Research funding from the Department of Defense for ballistics research.[59]

- **R&D Rebates**: In New Hampshire, a Senate bill currently in discussion would offer startups doing research and development the option to take advantage of a tax credit program through a partial rebate before they become profitable and owe any taxes. While R&D tax credits have set a historical precedent for economic development, many small enterprises are challenged to make use of them due to the lag between commercialization of innovation and profits.[60] As a result, many startups, especially within the first few years of their existence, can't take advantage of the credit and the access to capital tax credit programs afford. Similar to an existing R&D rebate program in Connecticut (the only current R&D rebate program in New England), SB 215-FN-A would allow businesses to choose to receive a rebate on their research and development tax credit instead of having that credit be used as an offset of their business profits tax liability. The rebate would be for up to 65 percent of the tax credit offered to the business, offering "fast and furious" startups a much needed injection of capital as they take their innovation forward.[61]

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[58] Wessner, C. "How Does Germany Do It?" *Mechanical Engineering - CIME*, November 2013. Abridged version re-published online by the American Society of Mechanical Engineers (ASME).
[59] "Tex Tech: Reinventing Itself Through Innovation," Maine Technology Institute website, http://www.mainetechnology.org/results/success-stories/tex-tech-reinventing-itself-through-innovation
[60] "Tax Reform Options: Incentives for Innovation - The International Experience With R&D Tax Incentives." Senate Testimony by the Organization for Economic Cooperation and Development (OCED), United States Senate Committee on Finance, September 20, 2011. http://www.finance.senate.gov/imo/media/doc/OECD%20SFC%20Hearing%20testimony%209%2020%2011.pdf
[61] Beland, A. "Proposed R&D Bill Aims to Aid Startups." New Hampshire Union Leader, March 2015.

As demonstrated through the examples above, using public funds in flexible ways to help small businesses scale up serves to "level the playing field" for these new and innovative small manufacturers. The key for supporting scale is flexibility, demonstrated by the ability to customize support to SME needs at the speed of business, and outreach, to proactively identify and conduct outreach to enterprises that would benefit from support to scale services. Through investments in innovation, research, technology transfer and adoption, and workforce development, policymakers can create an economic impact for SMEs that will continue to grow and return value over time as the organization scales within the advanced manufacturing ecosystem; in doing so, a support to scale approach to SME development may outpace many of the longstanding incentive and training programs that exist in today's economic development toolbox.

Opportunity: Collaboration Hubs and Start-Up Support

Alongside the SMEs that serve as vendors to the larger manufacturing supply chain exist innovative start-ups and early stage companies that are adapting next generation technology, processes and tools to the advanced manufacturing marketplace. These start-up SMEs often suffer similar challenges to those previously discussed, but in many cases, they also operate more optimally within a collaborative environment that pools shared resources (such as plant, facilities and equipment) and provides a built-in, consistent exposure to similar small businesses of an entrepreneurial flavor.

One common way of spurring collaboration is through start-up incubators and collaboration hubs. The cross-pollination of ideas and resulting knowledge spillovers that occur in this collaborative environment feeds the innovation and commercialization processes for SMEs, while providing a micro-environment for these types of SMEs to prosper and grow at an operational level. An incubator can be particularly effective for entrepreneurs to get started in a capital-intensive, competitive industry such as manufacturing. Some examples of incubators and start-up support programs within the New England region include:

- **Collaboration Hubs as Innovation Spaces**: In Rhode Island, the Founders League is a collaboration hub for start-ups located in the heart of the Knowledge District in Downtown Providence. Formed from a partnership of Betaspring, a mentorship-driven startup accelerator program for technology and design entrepreneurs, the Greater Providence Chamber of Commerce, the University of Rhode Island, and Brown University, the hub features co-working space, collaborative networking, educational programming, start-up assistance, and funding support for its members. Memberships are flexible, and can be purchased in increments of as little as a daily pass for access to the facility and its benefits. According to Entrepreneur Providence, the Founders League is one of eighteen spaces in the city that serve as a collaboration hub, and bridge the space between living and working for start-ups and entrepreneurs.
- **Academia-Sponsored Incubators:** The Advanced Technology and Manufacturing Center of the University of Massachusetts-Dartmouth is housed within a 60,000 sq. ft., state-of-the art facility located in the South Coast Research and Technology Park, near Fall River. The goal of the ATMC is to provide advanced technology and manufacturing solutions, through industry and university partnerships, to meet current and future business needs. In addition to partnering with industry to produce leading research on coastal systems technology and bioscience focus areas such as micro-fluidic prototyping and commercialization, the incubator also supports technology start-up ventures, delivers educational and technical assistance programming, and helps students and faculty to produce and commercialize their research.

  Another academia-sponsored initiative is UMass-Amherst's Center for Hierarchical Manufacturing (CHM), which includes a national research center focused on state-of-the-art roll-to-roll nanomanufacturing. Building upon Western Massachusetts' industrial legacy of sheet and web production of paper, film, coatings, and converting processes, roll-to-roll makes the previously impossible – printing products as small as a few nanometers – possible.[62]

[62] "UMass Amherst Nanotechnology Center Receives $20 Million Renewal of Federal Grant to Boost Advanced Manufacturing, Economic Growth." Center for Hierarchical Manufacturing, University of Massachusetts-Amhert. Website. http://chm.pse.umass.edu/node/83

- **Cross-Sector Innovation Collaboratives**: The Rogers Innovation Center is a unique academic-industry partnership between Northeastern University's Kostas Research Institute for Homeland Security and Rogers Corporation, a global materials technology leader. Located within Northeastern's Kostas Research Institute, the 4,000 sq. ft. collaborative facility is focused on the development of materials-based solutions to address homeland security-related challenges including clean energy, safety and protection, and Internet connectivity. In addition, the Center is tasked with rapidly commercializing new technological breakthroughs in order to accelerate the pace of innovation in the marketplace. The co-location of Rogers' R&D team and marketing professionals along with Northeastern's solution-driven research professors and scientists facilitates discussion around new technologies' uses from multiple shareholders' perspectives. This multifaceted approach to innovation helps ensure that new technology development is vetted from all angles, enabling a fluid transition from research and development through commercialization. As a result of the partnership, Rogers informs Northeastern's researchers about the products demanded in the marketplace, allowing researchers to focus their efforts on generating practical breakthroughs for which there is a current need. This "use-inspired" research goes beyond traditional license-centric or subscription-centric models and helps Rogers to quickly bring new technologies to market, creating a mutually reinforcing partnership for innovation.

- **Technical Assistance to Protect Intellectual Property**: Small and medium-sized businesses in particular can lack the infrastructure to support commercialization of their technology innovations past ideation (i.e., legal resources to adequately review large numbers of legal agreements). In order to optimize the value emerging from SME startups participating in incubators and collaboration hubs, IP principles designed with the goal of accelerating technologies into the marketplace are needed to help minimize negotiations and reduce transaction costs associated with IP after invention, thereby decreasing the burden of IP management for the businesses and the incubators.

  Accessible technical tools such as standard agreements and principles, particularly those surrounding the confidential treatment of background IP, pre-existing data, and generated data, need to be established to give SMEs support and protection to participate. The Advanced Manufacturing National Program Office (AMNPO) Intellectual Property (IP) task team, associated with the President's National Network for Manufacturing Innovation Initiative (NNMI), has formulated guidance associated with the establishment and operation of NNMI Institutes around the country that aligns to the principles of the Bayh-Dole Act regarding patents, trademarks, and copyrights,[xxiii] and has received validation by industry leaders through an extensive public input process.[63] These guidelines may well serve as a basis for New England to extend efforts to protect IP for the region's startups and manufacturing innovators.

[63] "Guidance on Intellectual Property: National Network for Manufacturing Innovation," Advanced Manufacturing National Program Office, March 2015.

Homegrown innovation: Vermont's rising collaboration hubs

Burlington, Vermont has become a magnet for technology collaboratives and start-up incubators. The Generator, a non-profit maker space and "design and fabrication sandbox" housed in a city-owned annex in Downtown Burlington[64], provides shared studios, computers, a 3-D printer, laser cutter, sand blaster and other tools accessible by its 47 members, who are comprised of mostly small manufacturers with customized product or design. To date, the Generator has spawned seven businesses through access to the "rapid prototyping" tools and shared business support available there. Success attracts success - Generator represents one of several recently formed startup accelerators, co-working spaces and maker spaces in Burlington.

The Vermont Center for Emerging Technologies (VCET) provides its members startup experts, a robust mentor and investor network, education programs, and three high impact co-working spaces in Burlington, on UVM's campus and in Middlebury. Members of the VCET portfolio include smart grid technologies, transportation start-ups, and even consumer goods and baby products. Ranked #11 globally in the 2013 UBI Index, VCET has directly assisted over 900 entrepreneurs thus far. Cumulative impacts from the 43 firms in VCET'S portfolio include $72 Million in revenue, $54 Million in payroll, $76 Million in capital, and 44 internship placements. VCET will soon add another incubator space to its footprint, managing the new VCET @ BTV, to be housed on the second floor of a FairPoint Communications facility in Burlington.

MakerLab at Champlain College near Burlington allows students, faculty, staff and alumni to access to 3-D printers, a 3-D scanner, a laser cutter, a vinyl cutter, two large format photo printers, a high-end sewing machine, and a wide-array of more traditional hand and power tools. The maker space also houses an electronics lab where users can learn about and operate micro-controllers like the Arduino and Raspberry Pi. These tools, as well as sensors, motors and other electronics are even available for checkout to entrepreneurs for use in their projects. Additionally, through a partnership with the Generator, Champlain students can access to even more tools.

Given the collaborative integration between government, industry, and education in Burlington, the maker spaces, collaboration hubs, and start-up incubators that have sprouted in this area are sustaining a growing entrepreneurial ecosystem, one where the collaboration hubs not only reinforce their members, but one another. In doing so, Burlington, VT is demonstrating an effective grassroots model of support to scale for innovative businesses in advanced manufacturing and beyond.

Photo Credit: Generator Vermont, Vermont Public Radio

With collaboration at the heart of advanced manufacturing, protecting intellectual property is a paramount concern, especially when more than one company is jointly participating in a collaborative design or effort. Likewise, academic institutions and other institutions are hesitant to undertake the legal risks involved in having students signing non-disclosures, and other measures to keep competitive information in-house. One area where there is a clarion call for additional policy action is in the arena of IP protection, as gains made here will reinforce existing collaborative efforts, and allow the collaboration model of business development to replicate across the region.

If the hallmark of advanced manufacturing and the thing that differentiates it from traditional "old' manufacturing is the application of innovative tools and methods to accelerate productivity, then early stage and start-up SMEs are the DNA of the industry's growth. Rather than relying on large firms with dedicated R&D divisions to commercialize their innovations (or not), nurturing these businesses will introduce organic innovation into the marketplace more rapidly and further support the advancement of advanced manufacturing machinery and production methods.

[64] Burbank, April. "Burlington Maker Space is Growing," *Burlington Free Press*, October 2014.

Challenge: Alignment of Stakeholders to Support Industry

During the course of our interviews with industry stakeholders and policymakers, a large majority of the individuals we spoke with echoed nearly identical sentiments about the challenges facing advanced manufacturing and the many efforts that have been launched across the industry landscape to address those challenges. One opportunity for development that emerged from those discussions was a need for ecosystem partners (educators, policymakers and manufacturers) to strengthen their relationships with one another within and across state lines, and leverage that strength to both improve their programming and pursue resources and funding more effectively.

New England has always been a collection of independent states with strong individual identities, but to some extent this perception of independence may be working against the region's best interests: anecdotal evidence suggests that the prior round of Federal NNMI funding to designate Centers for Advanced Manufacturing Innovation across the country awarded Center designations based on the differentiation of strong inter-connections and evidence of cross-sector collaboration between neighboring states, as well as between industry, education and government demonstrated consistently over time.

Through our conversations, it is clear that the six New England states want many of the same things for their constituents and employ similar approaches to addressing their challenges within their borders. The proposition that remains for the six states is to determine how to employ collective action across administrative and jurisdictional boundaries to unify and scale the existing "islands of excellence." These programs are already making an impact locally, but must organize into a regional program that showcases the New England's strength and collaborative spirit in future advanced manufacturing pursuits.

Opportunity: Adopt a Regional Mentality

The perception of New England as a political entity unto itself has the potential to influence policy issues relevant to the advanced manufacturing industry; indeed, more than six smaller states acting individually could. In fact, many economic areas for advanced manufacturing bleed across state borders.[65] Economic areas such as Western Massachusetts/Northern Connecticut, Western Connecticut/New York City/Hudson Valley, and Rhode Island/Eastern Massachusetts/Southern New Hampshire and Vermont, and the I-91 Corridor give credence to the notion that with respect to macroeconomic and regional infrastructure issues, advanced manufacturing may do well to assess which funding, investments, and policy directives will optimize industry performance across the region. Throwing political support to those priorities with the collective impact of a regional industry consortium could affect change.

State leaders interviewed for this report acknowledged that while they make a diligent attempt to understand what is happening in their own backyard (and perhaps just across the fence), they desired the opportunity to connect more with their counterparts in other states to dialogue about ways to affect policy that would enhance the region's standing. Despite the fact that the states do maintain some aspects of competition in terms of economic development, they also recognize the value of sharing leading practices (see Appendix B – Islands of Excellence), and taking a "bigger picture view" of regional prosperity with respect to the advanced manufacturing industry cluster.

This kind of cross-border collaboration represents a critical ingredient to a successful NNMI grant submission. Given the mutual desire of the six states and their respective ecosystem partnerships to achieve the same aim (a robust and sustainable environment for advanced manufacturing to prosper), an effort to convene and align stakeholders and focus them on a unified agenda for growth may be the first step in a series of powerful activities to position the region rather than the sum of its parts.

[65] *US Cluster Mapping Tool*, Harvard Institute for Strategy and Competitiveness, 2015. http://www.clustermapping.us/cluster

NMMI: A collective investment in America's next generation of makers

The National Network for Manufacturing Innovation (NNMI) is an initiative launched by the Obama Administration in 2013 to fund a series of advanced manufacturing hubs across the country. Each hub focuses on a different process or function of manufacturing; institutes funded thus far include additive manufacturing/3D printing, wide bandgap semiconductors, and integrated digital design and manufacturing, among others. President Obama has called for 45 of these institutes to be established over the next decade, and in December 2014, he signed the Revitalize American Manufacturing Innovation (RAMI) Act into law, codifying the process for growing the number of NNMI centers nationwide into statute.

NNMI hubs conduct research and development, conceptualization, and prototyping, as well as work on time, cost, and risk reduction involving the commercial application of technologies and processes. As the President's Council of Advisors on Science and Technology (PCAST) wrote in its October 2014 report *Accelerating U.S. Advanced Manufacturing*, "Because these institutes would be hubs for the nation's leading experts in individual technologies, they would be able to translate technology breakthroughs into products and businesses for the market, and form effective teams of industrial and academic experts from multiple disciplines to solve difficult problems from pre-competitive research to proprietary technology or products development."[66]

Additionally, NNMI hubs create opportunities to train the future advanced manufacturing workforce at a time when the nation faces a growing skills gap. By exposing more Americans to the high-paying, highly skilled jobs of manufacturing, NNMI can act as an agent to improve the prospects for the sector's continued success and a national economic rebound.

According to the President, "We are looking for businesses and universities that are willing to partner together to help their region -- help turn their regions into global centers of high-tech jobs. Because we want the next revolution in manufacturing to be "Made in America."[67] In essence, NNMI hubs tap into the collaborative power of manufacturing stakeholders across a region. By establishing a nationwide network of these innovation centers, industry, nonprofits, and academia will have an effective and responsive research infrastructure, a "teaching factory" that allows them to solve relevant challenges related to advanced manufacturing, including those addressed in this report.

MAKE IT IN AMERICA

Photo Credits: Whitehouse.gov, Manufacturing.gov

Opportunity: Align Policy with the Needs of Industry

Tax incentives, seed funding, matchmaking, export assistance, workforce training grants and infrastructure investment are all tools used by government to provide the "right" business environment for companies. Manufacturing maintains high, capital-intensive barriers to entry and promoting new entrants and encouraging what can often be expensive upgrades and innovation for current companies is not an inexpensive proposition. Most states with a sizeable tax base maintain some arsenal of economic development and workforce development incentives to attract, retain and grow businesses in key industry clusters such as manufacturing; unfortunately, our conversations revealed a number of gaps between what is offered, what gets utilized, and what makes an impact.

Our discussions revealed a pattern of piecemeal programs that, while beneficial, were inconsistently funded year-over-year, and had varying levels of utilization by the firms they are targeted to support. Most of those interviewed acknowledged that traditional tax incentives are insufficient to swing the pendulum in terms of a site selection or expansion decision; however, in numerous states, concerns over Southern states with lower corporate costs and a bevy of incentive packages luring New England companies away (mostly

[66] Report to the President: Accelerating U.S. Advanced Manufacturing. President's Council of Advisors on Science and Technology, October 2014. http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/amp20_report_final.pdf
[67] Speech, President Barack Obama, May 9, 2013. http://www.whitehouse.gov/photos-and-video/video/2013/05/09/president-obama-speaks-innovation-and-manufacturing

through expansion efforts in different regions) were enough to keep policymakers alert to the business case for aligning available funds and programs directly to the needs of businesses located throughout the region.

With respect to manufacturers, most industry firms sought flexible workforce training dollars or placement assistance to recruit and train the talent they so desperately need to sustain and grow their business. Many firms, particularly smaller employers, lamented the level of bureaucracy required to apply for support, and the onerous levels of reporting and monitoring required to remain in compliance. Coupled with a timing lag from application to funding that stretched into months, the funding available was often either too inflexible, not timely, or too cumbersome to manage once awarded for not enough outcome in terms of stable, well-trained employees.

Policymakers also acknowledged that they had to "get creative" to make tools and funds available work for companies at the speed and level of flexibility that they needed to be successful. Given the high cost of locating operations in New England, and the fact that many of these tools are funded with Federal dollars, it may behoove New England to consider sharing creative approaches to aligning tools and incentives while organizing as a region to request additional consideration or flexibility in the application of Federal dollars to State economic development needs.

Opportunity: Aggregate and scale the "Islands of Excellence"

Throughout the development of this report, we identified numerous examples of policy interventions and innovative programs that have originated in each state to address challenges to the advanced manufacturing industry. The term "islands of excellence" conveys the limitations of these standout programming efforts; while many of them serve a small or localized group of recipients in a manner that aligns quite closely with what industry, government and educators are clamoring for, either funding, sphere of influence, or available bandwidth constrain these successful models from replicating and scaling at the level required to affect systemic regional change. While some of New England's islands of excellence are highlighted within this report, many more such accomplishments received mention during our interviews and these are highlighted in Appendix B at the conclusion of this document.

So many programs have been created and customized to serve the advanced manufacturing industry at various levels of scope that the sheer volume of opportunities seems overwhelming. At present, it is unclear the extent to which this patchwork of innovative programs addresses the holistic needs of the region and of advanced manufacturers, and in all likelihood, there are opportunities to optimize across similar programs where shared services or resources could be leveraged rather than operated in parallel. Given the pressing industry need that has given rise to these programs, and the vast amount of public and private resources that are being dedicated to make them successful, an opportunity for New England exists to aggregate these "thousand points of light" into a cohesive picture of what is being done in the region, identify where (if at all) additional focus is needed to close gaps in the programmatic landscape, and centralize some of the scalable and replicable models that currently exist to be adapted where demand exists.

By understanding the industry needs that drive these programs' creation, as well as the programs and leadership themselves, the New England region can develop a "bird's eye view" of the programs currently in place, optimize scarce resources to fill gaps where they exist, and strengthen ecosystem partnerships across programs and across states.

Challenge: Complexity of the regulatory environment on business

Regulation as an activity is called out separately from other policy and incentives above due to the fact that it was cited frequently as an input to the cost of doing business in New England that fell under government's direct power to change. Rather than arguing for a removal of regulations or an overall relaxation on regulatory activity, most manufacturers acknowledged that regulation is necessary, but voiced concerns over the complexity of compliance with overlapping layers of regulation for which they must report, characterized by some as a "choking thicket" of rules[68].

[68] Woolhouse, M. "Make Growth for Small Businesses Easier by Cutting Away Choking Thicket of Rules," *Boston Globe*, 2014.

One respondent said “It’s hard to know all of the regs that apply to my business, much less keep track of the reporting calendars for compliance, the forms, the metrics, and so on.” Many advanced manufacturers acknowledged hiring regulatory consultants on retainer to support the monitoring, reporting, and compliance processes required to maintain mandatory licensures and accreditations – this added a fixed overhead cost which was deemed by many to detract focus from product and operational matters. In a Boston Globe article profiling the challenges of regulatory compliance on SME operators, an interviewee named Kenneth Mandile captured the sentiment of the industry by noting, “Every time I have to spend money [on regulatory compliance], that’s money coming from another investment that could have been made that somehow benefits my customers or my employees.” Other firms interviewed for this report acknowledged similar trade-offs between the opportunity cost of contracting regulatory expertise (not to mention the cost of compliance itself) and the scope of the investment, which was sacrificed or diminished in light of regulatory costs.

An additional factor in the discussions around business regulation was the volatility of regulatory change and amendment at the governmental level, which left numerous employers feeling like they were powerless to effectively plan for the future. Other regulatory concerns centered on specific policies (such as the Affordable Care Act, mandatory paid sick leave, and other “blanket” regulations) that they felt dwindled their ability to compete for talent using flexible benefits, corporate taxation more generally, as well as confusing or seemingly irrelevant environmental regulations.

Without debating the necessity of regulations to protect citizens from the externalities of commercial activity, policymakers acknowledged that the regulatory environment in many New England states is complicated, and voiced the desire to simplify compliance at least, if not the regulatory environment itself.

Complex business regulations overwhelm small manufacturers

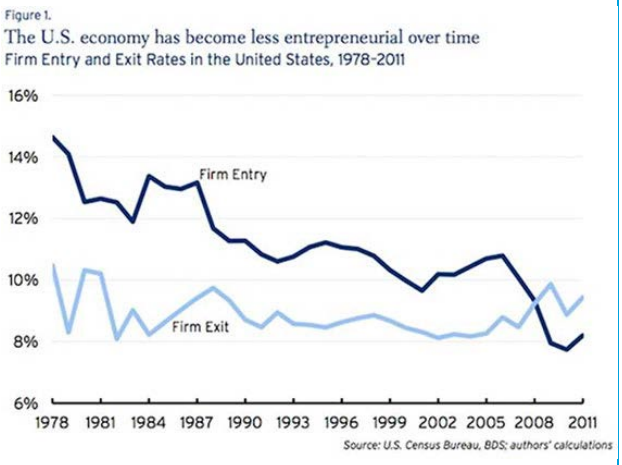
The effects of business regulation on advanced manufacturers are amplified in the SME community – Federal regulations, compounded with State regulations and local/municipal ordinances can create a patchwork of compliance requirements that significantly impact a small business’ operations and costs, to the detriment of small business growth.

In a recent *Boston Globe* feature on small business regulation, Kenneth Mandile, owner of SwissturnUSA, an Oxford, MA machine shop that makes precision Swiss screws for medical devices, guns, and pocket knives, recounted in detail the cost impacts of state regulation on a recent business expansion.[69] Mandile’s $2 Million warehouse expansion project encountered approximately $50,000 worth of unanticipated regulatory compliance costs, mostly around changes that did not result in any clear benefits for the company or for the public. Coupled with the challenges of running a business with less than 50 employees, complying with a “choking thicket of rules” and regulations proved an overwhelming experience to encounter for a project designed to grow the business.

While SME manufacturers are reticent to relocate from New England in response to regulation, they point out that there exist so many confusing layers of regulation, changing consistently over time, many must routinely hire consultants to interpret all of the regulations that the business is subject to, in addition to the actual costs of compliance. These additional costs to the business divert resources from investing in growth initiatives. According to Mandile, “Every time I have to spend money, that‘s money coming from another investment that could have been made that somehow benefits my customers or my employees.”

[69] Woolhouse, M. “Make growth for small businesses easier by cutting away choking thicket of rules.” Boston Globe, November 2014.

In doing so, the cumulative effects of regulation on smaller businesses potentially contributes to the dampening of entrepreneurial ventures in the overall economy. As examined in a recent study published by the Brookings Institute, business dynamism and entrepreneurship are experiencing a troubling secular decline in the United States across all regions. While business regulation cannot be shown to be the direct cause of this decline, the coincidence of increasing regulatory complexity during the time period examined, coupled with the fact that older and larger businesses seem to suffer less than smaller businesses (due to the ability to more readily absorb compliance costs), indicates that close attention must be paid to New England's SME manufacturers to remove barriers and create a favorable environment for small business and entrepreneurship.



Given that New England's advanced manufacturing cluster is made up primarily of SME businesses, policymakers and administrators are beginning to hear the clarion call for a "clear, predictable, reliable" set of business regulations and a streamlined process by which to comply.[70]

Photo Credits: SwissturnUSA, Brookings Institute

Opportunity: Simplify regulatory compliance

For New England, simplifying regulatory compliance represents another lever (beyond incentives or new programs) that policymakers can use to improve the climate for business within the region and demonstrate responsiveness to firms in key industry clusters.

Areas of focus (outside of altering regulations themselves) include: a) streamlining application and licensing processes, b) creating a "one stop" location or portal for companies to monitor their compliance with applicable regs, and c) simplifying reporting submission processes. Some examples of regulatory reform that may impact the advanced manufacturing industry are highlighted below:

- In 2012, the Rhode Island General Assembly passed a bill that required state agencies enacting regulations that impact small business to review at least 25% of the regulations on their books each year for four years, until all existing regulations were evaluated for adverse impacts to small business. The effort resulted in the streamlining of regulation overall, as well as tweaks to "archaic hurdles which serve as unnecessary hindrances to small business owners." [71] Last year, the Office of Regulatory Reform conducted an extensive mapping of over 1600 existing regulations, requiring business cases to be developed for those perceived as onerous to small businesses.
- Since 2011, Governor Paul LePage of Maine has pursued a similar campaign to revisit, streamline and substantiate business regulations on Maine's books, and in parallel, the Governor refocused the mission of the Department of Economic & Community Development by creating "Account Executives" a "Business 'Red Tape' Hotline," and small business "Ombudsmen" charged with helping job creators navigate the maze of government.

[70] Interview with Leslie Taito, Senior VP of New Business Development, Hope Global. January 2015.
[71] "Regulatory Reform Will Make the Difference." Press Release. Rhode Island General Assembly. January 2014. http://www.rilin.state.ri.us/pressrelease/Lists/oped/DispForm.aspx?ID=18

- In Massachusetts, in addition to the Baker Administration reviewing over 2600 regulations currently on the books, regulatory reform advocates are promoting the adoption of “guidance” and “guidelines” with which compliance is voluntary over strict regulations. This policy would permit companies for which compliance is not cost prohibitive (or in extreme cases, desirable) to comply, creating marginal gains towards desired regulatory outcomes while avoiding undue burden on smaller companies for whom additional regulation is burdensome.

In our discussions, business regulation was raised as a pain point, but one that industry stakeholders could see becoming more manageable through the adoption of predictable, streamlined processes and user-friendly tools that alleviate the need for small businesses to hire regulatory consultants and divert scare resources from growth, investment and innovation initiatives.

Challenge: Infrastructure, Energy and the Cost of Doing Business

The “cost of doing business” in New England was categorically discussed by those interviewed, but the tone of the responses indicated that this subject matter is tablestakes for any discussion about commerce in the New England corridor. The challenge is mentioned here in part because it has become such a pervasive element of commercial activity in New England; however, given the scope of this report and the larger context of the business climate in New England, our discussion of this challenge and recommendations will be limited to documenting an issue that has already received much attention at a greater level of detail.

New England faces several large business environment challenges for advanced manufacturers, not least of which are the high cost of real estate, energy, and transportation. In a capital and energy intensive industry such as advanced manufacturing, these challenges have costly implications for advanced manufacturers.

Electricity Cost by State for Commercial Users

Rank	State	2012 Average Price (cents/kilowatt-hour)
1	HI	34.88
2	NY	15.06
3	AK	14.93
4	CT	14.65
5	VT	14.32
6	MA	13.84
7	NH	13.36
8	NJ	12.78
10	RI	11.87
11	ME	11.53

With power prices in the region among the highest in the country, energy has a strong negative impact on the cost of manufacturing in New England. Five out of the six New England states have energy rates in the top 10 across the nation.[xxiv] In addition, energy shortages are exacerbated by congestion issues through the Northeast corridor for car, rail, and highway transport. Despite the large number of coastal states bordering the Atlantic, aging port infrastructure would need to be deepened and retrofitted to support commercial cargo, and avoid companies having to transport goods south to the port of Newark and beyond.

Figure 30: Electricity Costs of Commercial Users
Source: US Energy Information Administration, Detailed State Data, Total Electric Industry Providers

In interviews, we heard that the diversion of time and resources made weekly to defend against attempts by lower cost states to recruit New England companies to relocate or expand to the South, where infrastructural costs are substantially cheaper, even without the comprehensive incentive packages on offer. While resident companies were reluctant to consider a wholesale relocation of the business (often on the grounds that the talent in New England was superior and difficult to replicate), several noted that where

they had operations in locations outside New England, they were increasingly forced to site new projects at those locations for reasons of cost competitiveness.

As previously discussed, the current strength of the New England advanced manufacturing industry cluster is able to offset infrastructural costs somewhat; that said, one must ask how long that multiplier will sustain in New England, given the growth of manufacturing regions with more cost competitive climates, and the steady rise of input costs combined with the decline of infrastructure. The actions outlined in this report are intended to further strengthen the region's ability to thrive despite these challenges by focusing on the unique advantages we do have such as access to collaboration hubs, innovative start-ups, given the increased, a robust supply chain linking to international trade, and a leading educational environment that turns out some of the nation's most talented workers through its academic institutions.

Opportunity: Prioritize initiatives to drive down the cost of business in the region

Given advanced manufacturing's energy-intensive processes and export potential outside the region, infrastructural costs related to the business climate will likely continue to exert pressure on the industry and in turn, remain at the top of the agenda for policymakers. New England manufacturers should continue to align with one another on issues related to major infrastructure projects and energy generation initiatives, develop relief programs such as bulk buying and pricing initiatives for energy (as in Massachusetts, New Hampshire and other New England states) and maintain a steady dialogue with policymakers on the importance improvements in these areas have for the larger New England economy. For additional information regarding the topic of infrastructural issues affecting the New England business climate, please reference the 2012 report published by The New England Council and Deloitte Consulting LLP, *Smart Infrastructure in New England: An Investment for Growth and Prosperity*.

Optimizing Opportunities for Growth

The five challenges and related opportunities selected for this report are not intended to be an exhaustive list of those facing the advanced manufacturing industry, or the New England region as a whole. However, the topics addressed in these five areas represent the highest priority issues as identified by a diverse group of ecosystem stakeholders. To make progress on any one of them would result in a positive impact to the industry, and an uptick in growth and prosperity. Recognizing that resources are often scarce and only few things can be accomplished in parallel, the section that follows outlines a set of recommendations targeted at "moving the needle" towards improvement in the areas previously discussed.

New England's advanced manufacturers face obstacles to growth, but each New England state, along with the firms who do business there, are responding with a plethora of innovative programs, processes and policies. These initiatives can and should be replicated and scaled to create a strong regional program that can address New England's workforce and economic development challenges head-on.

Recommendations

Developing a thriving industry ecosystem

Bringing together all three main actors (educators, companies, policy-makers) to rally around the challenges outlined above and work collectively to create a vibrant economy for advanced manufacturing requires coordination, planning and leadership. Collaboration becomes essential because while all of the parties have stated nearly identical challenges to their local jurisdictions, and have outlined similar approaches to remedy those challenges, no one party is large enough now to dictate to the others how the game will be played.

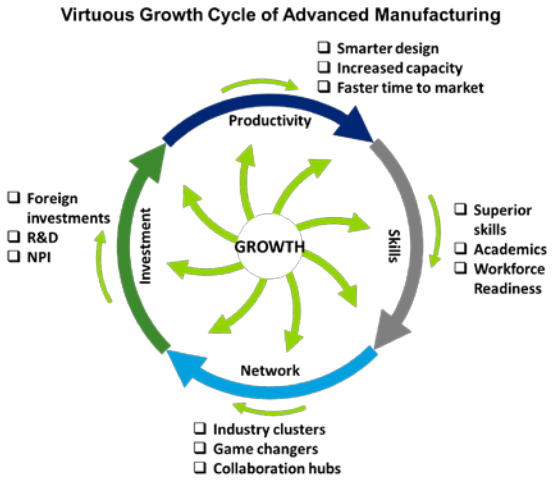


Figure 31: Growth Cycle of Advanced Manufacturing

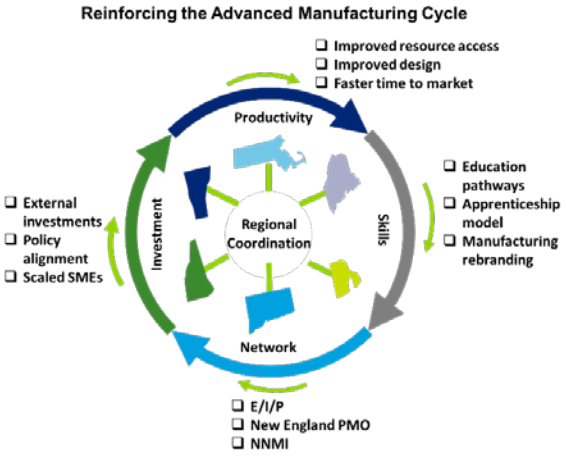


Figure 32: Reinforcing the Manufacturing Growth Cycle

A systemic approach

As detailed in the previous sections, there are many “islands of excellence” within the advanced manufacturing landscape that can serve as examples for others in the region. The challenge for New England is to bring these initiatives together in a manner that strengthens the region holistically. In order to capture the full value of these innovative approaches, a systemic approach to accelerating growth is required. A coordinated plan represents an effective way to move forward and move forward quickly. One idea to facilitate this regional coordination is to establish state program offices that coordinate with each other at the regional level. The intent is not to create a new, bureaucratic layer, but rather to have a central organizing force that can:

- Share information
- Evaluate programs and innovations to see what is working
- Facilitate expansion of programs that work
- Systematize the islands of excellence to be the way the region does and grows business

The primary focus of the program offices is to coordinate the efforts of the six key recommendations, shown below:

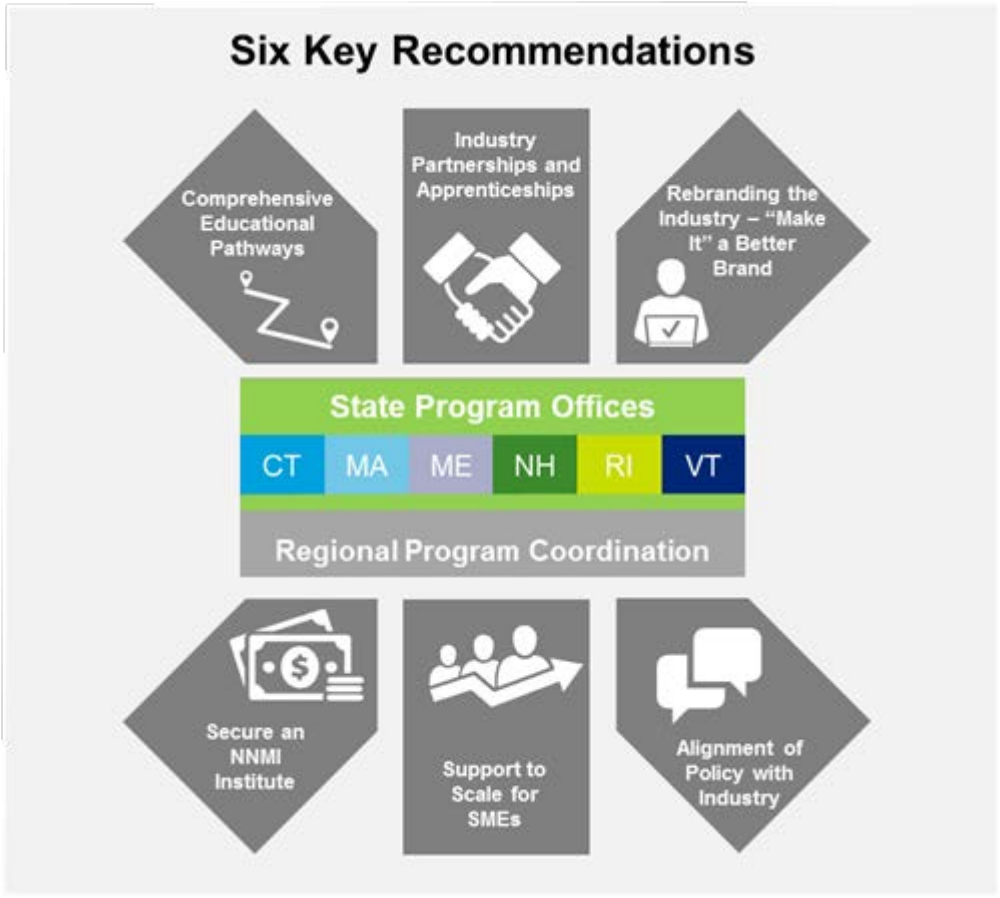


Figure 33: Six Key Recommendations
Source: Deloitte

While each New England state will oversee implementing the six main recommendations resulting from this report, the six states will coordinate their efforts regionally to streamline the workload and optimize collective impact. By addressing these opportunities across the region in a concerted way, New England can accelerate the growth of the manufacturing industry. Through the course of our research and discussions we have identified six categories of opportunity that, if fully shared and applied across the region, could be differentiators and serve as accelerators for growth:

- **Create Comprehensive Educational Pathways:** Crafting a fully connected system for the future workforce, one that begins with awareness and exposure before high school, and connects to a flexible variety of educational institutions, training, internships and work experience with transparency, transferability of credits, and multiple on-ramps and off-ramps to support lifelong learning at a multitude of educational levels.
- **Expand Industry Partnerships and Apprenticeship Model:** Creating, scaling and replicating existing connections between industry and educational institutions so that not only are more students workforce ready and aware of opportunities in the industry, but also so that new ideas from students permeate the industry, spurring innovation.
- **Re-Branding the Industry – "Make It" a Better Brand**: Moving away from the old view of manufacturing by changing the language we use around it – by pivoting towards the "maker revolution" where workers "design, make, and sell," New England can change the brand of "advanced manufacturing" to reflect the high pay, critical thinking, advanced technologies and designs that define it.

- **Secure an Advanced Manufacturing Institute for New England**: Building upon the lessons learned from the previous NNMI submission, New England can focus on strengthening statewide and regional collaboration within the advanced manufacturing ecosystem to forge strong connections between government, educators, and industry that will both accelerate industry growth while priming the region for the next round of grant applications.
- **Support to Scale**: Applying focus on the unique requirements and operating conditions of SME enterprises that are vital to the growth of the maker generation, and implementing policies and programs that allow these businesses to access resources that help them scale and serve a pivotal role in the advanced manufacturing ecosystem. Includes start-up hubs and shared resources that promote change through collaboration between various groups interested in promoting the industry of advanced manufacturing. Develop job matching and talent sourcing capabilities through the development of an aggregated job bank across the region.
- **Alignment of Policy with Industry:** Identifying creative and supportive policies, programs, and funding from state and local governments/institutions that foster growth in advanced manufacturing, including rationalization of policies, programs, incentives and regulatory mechanisms that impact the industry.

Action plan for New England

The recommendations outlined in this report are intended neither to be exhaustive nor comprehensive; rather, given feedback from New England stakeholders, they are intended to address the most pressing concerns facing the advanced manufacturing industry. For each recommendation, a series of suggested actions for each group of industry stakeholders has been proposed as a means of spurring further discussion and planning after this document is published. These suggested actions should be considered a jumping off point for further discussion, customization and action by the six New England States individually and collectively as they develop their go-forward plan.

Recommendation #1: Creating Comprehensive Educational Pathways

Description: Across the region, many programs exist to address educational pathways from K-12 awareness and hands-on learning through higher education, community college, and re-tooling the incumbent workforce. However, few of these programs are replicated statewide, limiting access to specific geographic areas within New England. Because the most enticing programs are defined from end-to-end with multiple on-ramps and off-ramps, as well as transferability of credit and industry-recognized credentials, this recommendation urges states to survey their internal advanced manufacturing landscape, and piece together a holistic model for workforce development.

Measure of Success: At least one defined pathway (Technical and Traditional High School → Community College → 4-Year Degree → incumbent upskilling / retraining), with internship and apprenticeship opportunities throughout the pathway in each New England state.

Suggested Actions for Implementation	
Policymakers	• Define within the state the career pathway for advanced manufacturing for citizens at all levels, and identify any gaps • Identify strategic profiles for candidate recruitment in to advanced manufacturing jobs; include diverse and non-traditional cohorts and determine how to match them to industry jobs • Convene stakeholders from industry, government and education to discuss gaps identified and programs to remedy them • Analyze existing workforce development funds and incentives to determine how they could be applied to build out the career pipeline more effectively using policy
Educators	**HIGHER EDUCATION:** • Assess current pipeline for community college transfers and transferability of credits; migrate to more flexible models of transferability where possible • Assess placement of graduates in advanced manufacturing employment post-

	graduation and strengthen ties to local area employers • Continue to sponsor capstone consultancies and student maker projects, house incubators and be the leaders for industry to academia innovation • Scale adoption of problem-based learning methods to grow student capabilities and transferable skills • Work with career services to strengthen intern and apprentice programs that lead to hiring **K-12 EDUCATION:** • Continue to reinforce STEM skills and essential skills amongst students • Scale adoption of problem-based learning methods to grow student capabilities and transferable skills • Assess the existence of a pre-high school awareness program for STEM, technical skills, and advanced manufacturing careers • Implement connection points to internship, technical education and apprenticeship at the high school level
Manufacturers	• Identify pathways to recruit candidates from high school, community college, and non-traditional cohorts (i.e., encore careers, long-term unemployed, veteran, incarcerated); if not already established, seek assistance from ecosystem partners to identify a replicable model that can be scaled to your business • Identify ways to connect with applicants who may be "screened out" of recruitment processes due to remedial education (i.e., 12th Grade math), and refer these interested individuals into "bridge" programs, either online or publically supported to improve their skills and retain them in the industry • Reach out to policymakers to assess availability of funding to support recruitment pipelines
State & Regional PMO	• Gather inventory of existing programs by state and support identification of gaps • Facilitate development of state pathway models with cross-sector representatives from each state • Share information on programs that are replicable and scalable from one geography to the next

Recommendation #2: Expand Industry Partnerships and Apprenticeships

Description: Industry partnerships and apprenticeship models are a valuable segment of the skills development pipeline for advanced manufacturing workers. While serving as a recruitment mechanism for industry employers, these partnerships can also be a way to conduct skills transfer to the next generation of workers. A recommendation to expand industry partnerships and apprenticeships will not only help position New England favorably for an NNMI Institute, but will also generate more opportunities to support SMEs and develop a critical mass of qualified workers to meet future demand.

Measure of Success: Increased job matching through industry and educational collaboration; each advanced manufacturing candidate secure a paid intern/apprentice opportunity.

Suggested Actions for Implementation	
Policymakers	• Analyze existing workforce development funds and incentives to determine how they could be applied to support the development of partnerships between industry, government and education
Educators	**HIGHER EDUCATION:** • Seek industry input and feedback on learning capabilities necessary for success in advanced manufacturing careers • Continue to expand and scale apprenticeship for credit and apprentice to hire programs • Engage in cross-pollination and innovation collaboratives with other academic institutions **K-12 EDUCATION:**

	• Develop partnerships with advanced manufacturers to increase awareness amongst students and faculty • Participate in apprenticeship programs to the extent applicable
Manufacturers	• Continue to support intern and apprentice-to-hire programs and scale existing initiatives • Contribute input to educators and policymakers about the skill sets needed to succeed in your business by students entering the job market • Provide meaningful, paid internship experiences that serve both the business and the professional development of the candidate
State & Regional PMO	• Inventory industry partnership and apprenticeship programs • Develop leading practices for successful cross-sector partnership and apprenticeship programs • Document learning capabilities and core curriculum models developed by New England states

Recommendation #3: Re-Branding the Industry: "Make It" a Better Brand

Description: Shifting perception of the "dark, dirty" brand of old manufacturing was one of the often most mentioned recommendations by those interviewed to address the skills gap; however, efforts to date have relied on traditional media, and appealing to an audience that no longer consumes information in a traditional way. Re-branding the industry is not just about pivoting to take advantage of the popularity of the "Maker Movement," but is also about understanding what the emerging workforce actually wants in their work and linking those desires to the opportunities that exist in advanced manufacturing, deploying the messaging in a manner that gets students, parents and educators where they are right now.

Measure of Success: Deployment of a marketing campaign region-wide; Increased rate of job matching of students to vacant positions

Suggested Actions for Implementation	
Policymakers	• Sponsor a marketing firm to develop a unique "guerilla marketing" campaign to target Millennials and their families across the region and shift brand perception of advanced manufacturing using multiple media channels • Disseminate the marketing/branding campaign across the region at low or no cost to states as a shared resource to leverage
Educators	**HIGHER EDUCATION:** • Educate college career counselors and career services office staff with the employment opportunities in advanced manufacturing and how they relate to collegiate programs • Conduct outreach to manufacturing partnerships to connect students to internship opportunities • Promote advanced manufacturing in career fairs and campus recruiting events **K-12 EDUCATION:** • Meet with advanced manufacturing firms, tour their offices, and learn about the industry and how your students can benefit • Support "maker spaces" and on-site technical activities in the school for students to participate • Collaborate with industry to learn how to incorporate advanced manufacturing awareness, events, and coursework into your class curriculum
Manufacturers	• Assess what next generation workers want in their career and how that may differ from what advanced manufacturing is offering; conduct 360 feedback or focus groups to determine how the organization is perceived by young people and what could be done internally to change that perception • Collaborate within industry to develop a standard "Design.Make.Sell" course curriculum

	that can be flexibly adopted in K-12 settings. • Continue to sponsor middle/high school "make it" competitions and experiential learning events • Highlight and profile the young people who intern and apprentice at your organization in media campaigns to "change the face" of today's workforce • Extend referral bonuses to employees who successfully refer their next-generation peers
State & Regional PMO	• Facilitate the design and development of the "Design.Make.Sell" curriculum with cross-industry partners • Facilitate the data gathering and requirements development for the "guerilla" marketing campaign targeted to emerging workforce participants • Track data related to proliferation of "game-changing" events that shift the lens of advanced manufacturing sponsored by stakeholders and metrics related to student perceptions

Recommendation #4: Secure an NNMI Advanced Manufacturing Institute for New England

Description: New England's past bid for an NNMI Institute had a solid value proposition, but could be strengthened through a deeper demonstration of regional cohesion across state lines, and stronger intrastate partnerships between government, educators and industry. New England has a vast inventory of programs in place, and this recommendation supports aggregating the work in progress, documenting it, identifying and closing gaps, and strengthening the connective tissue of collaboration between ecosystem partners through the effort to develop the NNMI submission.

Measure of Success: Successful bid for an NNMI Manufacturing Center of Innovation located in New England in an upcoming round of RAMI funding

Suggested Actions for Implementation	
Policymakers	• Convene state leadership from across the region to discuss an approach to New England-wide collaboration and NNMI value proposition • Assess (by state) the collaborative landscape between government, industry, and educational institutions; examine the inventory of initiatives, and identify opportunities to close gaps and leverage regional models of excellence • Analyze within each state the landscape for advanced manufacturing in terms of policy, programs, incentives, and grants to assess degree of fit for industry; identify opportunities • Identify a working group for NNMI grant submission and convene a "lessons learned" session based on prior attempt.
Educators	**HIGHER EDUCATION:** • Increase collaborative dialogue with advanced manufacturing programs and incubators in neighboring institutions • If an in-house collaboration initiative exists (i.e., apprenticeship model, industry partnership), document and make the model available to others with guidance on how to implement • Identify an anchor institution that will represent the NNMI grant submission **K-12 EDUCATION:** • Reach out to state MEP, manufacturing collaborative, and/or community college district to discuss opportunities to collaborate, including awareness-building activities for students
Manufacturers	• Identify and mobilize manufacturing advocates and evangelists within each state to educate local, regional and state policymakers and educators on the current state of advanced manufacturing and NNMI effort • Document existing cross-sector partnerships with educational institutions and government; identify areas of opportunity to improve collaboration • To the extent feasible, plan or begin collaborative efforts with education institutions,

	leveraging existing models that are successful in the region • Identify a diverse cross-section of advanced manufacturing anchor employers and SMEs to be represented in the NNMI grant submission
State & Regional PMO	• Act as a convener for cross-state meetings and discussions • Create and disseminate briefing packets for manufacturers to use to educate local leaders and educators • Aggregate inventory of cross-sector partnerships and analyze gaps • Serve as a coordinator for the NNMI Working Group

Recommendation #5: Support to Scale

Description: To address the unique challenges of small and medium-sized manufacturers, correcting market failures where they exist, and creating a supportive environment that is accessible for SMEs to facilitate technology transfer, commercialization of small business innovation, tech adoption and training, workforce development and other forms of scaling the SME enterprise. Support to scale in this instance includes the development of a talent matching system, or job bank to link qualified candidates with opening and referral opportunities within the SME ecosystem.

Measure of Success: Increased location quotients of SME manufacturers across industry sub-sectors by 20% over five years

Suggested Actions for Implementation	
Policymakers	• Assess the efficacy of small business innovation and development policies for usability by SME manufacturers – Export Assistance – Innovation grants / seed funding – Matchmaking to business partners – Workforce recruitment assistance – Workforce training programs • Identify gaps in SME support landscape and MEP capacity and direct resources to programs with high ROI outcomes • Dialogue with other states to determine “creative” ways to structure programming for SME manufacturers • Promote technical assistance and outreach services to SMEs to support navigation of the paperwork and process to apply for benefits • Support legislation for R&D rebates, applied research, and other initiatives that help “level the playing field” for SMEs. • Support legislation for IP protection for start-up ventures at innovation incubators and collaboration hubs
Educators	**HIGHER EDUCATION:** • Promote research / business incubators co-located with campuses • Support applied research initiatives that connect academics with manufacturers for mutually beneficial collaboration and R&D support • Share leading practices in innovation with other institutions to improve and differentiate offerings • Share IP protection leading practices for early stage innovation and start-up companies **K-12 EDUCATION:** • N/A
Manufacturers	• Contribute to the development of a job bank, and communicate openings and referrals to help qualified workers find a “home” in New England advanced manufacturing high-demand areas, including: – Manufacturing Engineers

	– CNC Operators – Software Programmers – Automation Specialists – Master Schedulers – Master Scheduler Production control / Production Controllers – Supply Chain Experts – CAD/CAM/MES • Consider referring talent in excess of hiring quotas to local MEP organizations so that they can be referred to SME employers with similar staffing needs • Develop mentorship relationships with SME vendors to support tech adoption and tech transfer
State & Regional PMO	• Design a structure and supporting process for the talent matching system • Document leading practices to address needs of SME manufacturers • Develop webinars on tech adoption and technical assistance topics that can be used to host regular SME gatherings virtually

Recommendation #6: Alignment of Policy With Industry

Description: Foundational to the advancement of the New England region, alignment of policymakers with one another and with their ecosystem partners in education and advanced manufacturing both within and across state lines is necessary to successfully accomplish this suite of recommendations,

Measure of Success: Increased industry participation in programs targeted to grow advanced manufacturing by 20%.

Suggested Actions for Implementation	
Policymakers	• Within each state, convene cross-agency stakeholders in Labor, Economic Development, Education and Small Business to discuss policy that affects the industry in a holistic setting • Within each state, identify and connect with advanced manufacturing industry representatives to gather inputs to support policymaking activity • Reach out to peer-level counterparts in other New England states to build working relationships • Participate in convenings of state leadership to discuss advanced manufacturing in New England • Represent the region in addition to the state when working with Federal government and Congress
Educators	**HIGHER EDUCATION:** • Participate in cross-sector partnership discussions with industry and government regarding learning capabilities, maker and technical curriculum, internships and apprenticeship programs, and educational opportunities which advanced students academically and professionally. • Contribute perspectives on technical education and industry-relevant learning capabilities, as well as challenges to technical education to policymakers **K-12 EDUCATION:** • Participate in cross-sector partnership discussions with industry and government regarding learning capabilities, maker and technical curriculum, internships and apprenticeship programs, and educational opportunities which advanced students academically and professionally. • Contribute perspectives on technical education and industry-relevant learning capabilities, as well as challenges to technical education to policymakers
Manufacturers	• Actively communicate challenges and resource needs to policymakers at the local, state and Federal level. Be the drivers of policy alignment by gathering diverse industry data points and sharing them broadly.

	• Educate policymakers on the impact of advanced manufacturing in your state • Contribute to talking points that represent the industry in a manner that feeds streamlined messaging by manufacturers to government and educational stakeholders.
State & Regional PMO	• Aggregate data points from industry representatives and develop standard briefing materials and talking points to support unified messaging by many industry stakeholders

Conclusion – looking ahead

Five years from now, in 2020, what will advanced manufacturing in New England look like? Perhaps the region will resemble a global manufacturing hub – each state enjoying an unprecedented level of prosperity resulting from innovative products, tools and methods emerging from the region's many leading institutions and the start-up incubators they house as a standard practice.

These innovations and the knowledge spillovers erupting from the collaborative environments in which they arise can empower the next generation of makers to launch their own small business enterprises, which they are able to do effectively given the enhanced infrastructure to support them. As these emerging powerhouses scale up and link to the global supply chain, they are able to further transform their business models to continually increase productivity and feed the cycle of growth that permeates the region.

In this future, advanced manufacturing in New England has become a case study of using regional economic clusters and collective action across state boundaries to fashion a flexible, lifelong career pathway for learning, training and employment. As early as elementary school, children gain exposure to the advanced manufacturing industry that is an important component of their community, and by the time they are of working age, they compete for the opportunity to secure one of the exciting and well-compensated careers within the industry. Flexible development pipelines that support lifelong learning and career development can make this workforce possible, along with the New England Institute for Advanced Manufacturing and its regional hubs developed with NNMI funding.

This version of the future is attainable for the stakeholders in the ecosystem. By working together to tackle the most pressing challenges facing the industry, what begins as a collaborative conversation amongst colleagues today has the potential to create industry-transforming impact for the New England region tomorrow. We hope that you will join us in making the future described above a reality for advanced manufacturing and for New England.

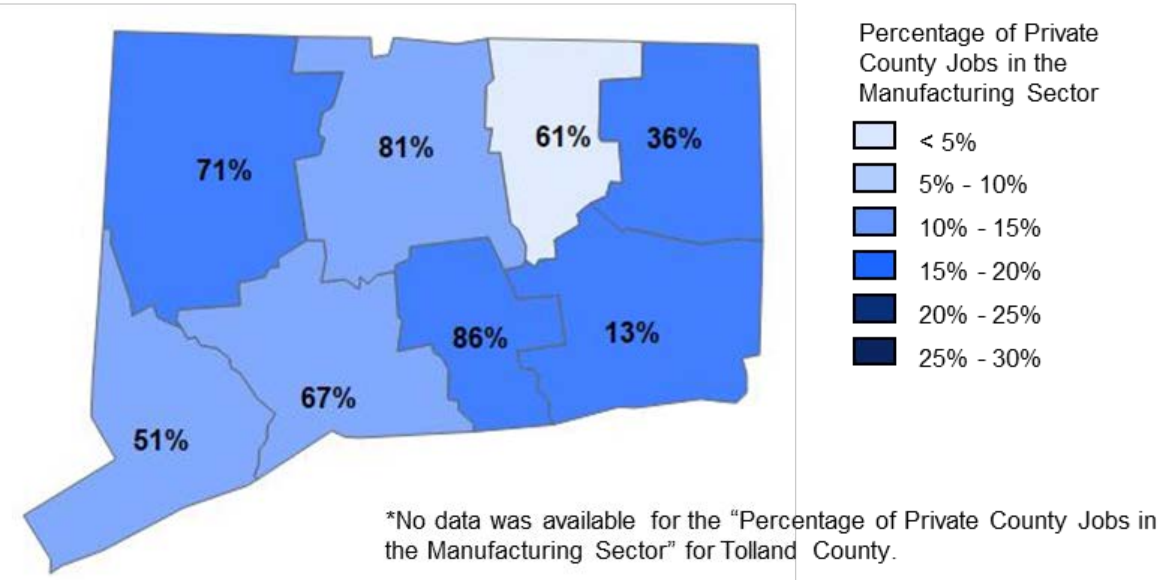
Appendix A

Snapshot of manufacturing in Connecticut

As illustrated in the map below, the employment impact of the manufacturing industry is far reaching across all of Connecticut, and is particularly significant in Litchfield, Middlesex, New London, and Windham Counties (greater than 15% of private jobs). Additionally, advanced manufacturing jobs represent over 60% of all manufacturing jobs in five of the eight counties.

Connecticut Profile	
Population	3.6 million
Total Jobs	2.2 million
Total Manufacturing Jobs	173,448
Total Advanced Manufacturing Jobs	124,754

Percentage of County's Manufacturing Jobs that are classified as Advanced



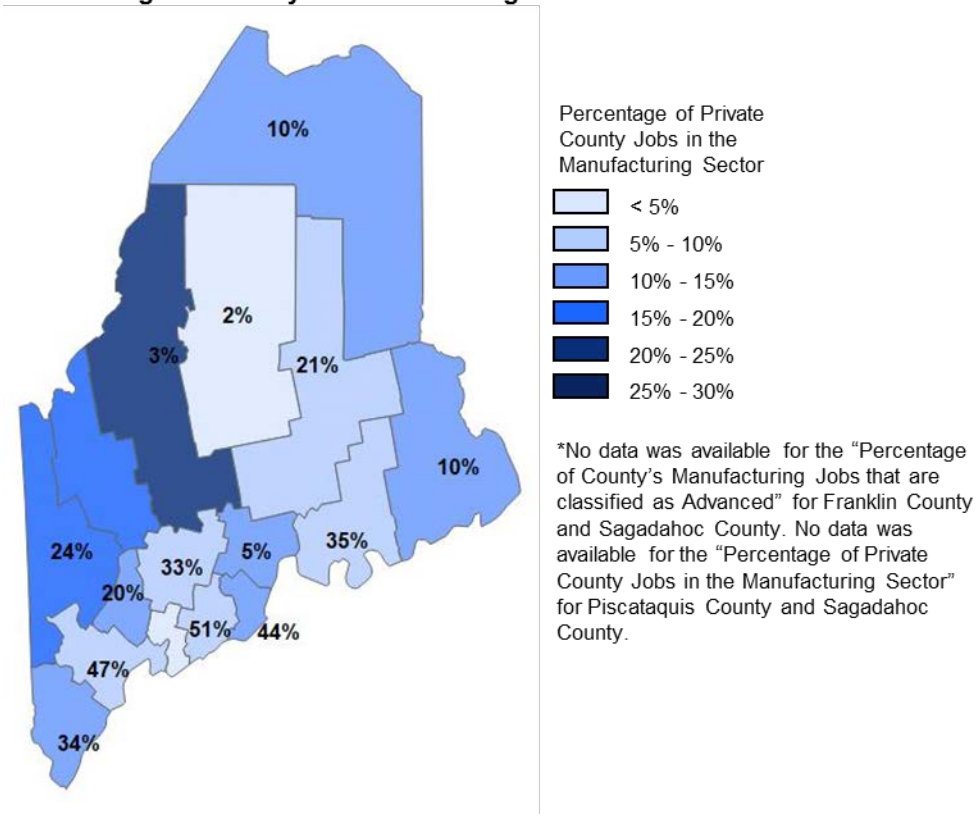
Source: US Census (2012), Bureau of Economic Analysis (2012), Bureau of Labor Statistics (2012), Deloitte Analysis

Snapshot of manufacturing in Maine

The map below displays the spread of manufacturing employment across the state of Maine, and highlights the importance of the industry in Somerset County, where greater than 20% of citizens are employed in manufacturing. The map also displays the significance of advanced manufacturing jobs in the state, as more than 20% of all manufacturing jobs in nine counties (primarily in the southwest portion of the state) are classified as advanced.

Maine Profile	
Population	1.3 million
Total Jobs	797,097
Total Manufacturing Jobs	55,667
Total Advanced Manufacturing Jobs	22,278

Percentage of County's Manufacturing Jobs that are classified as Advanced



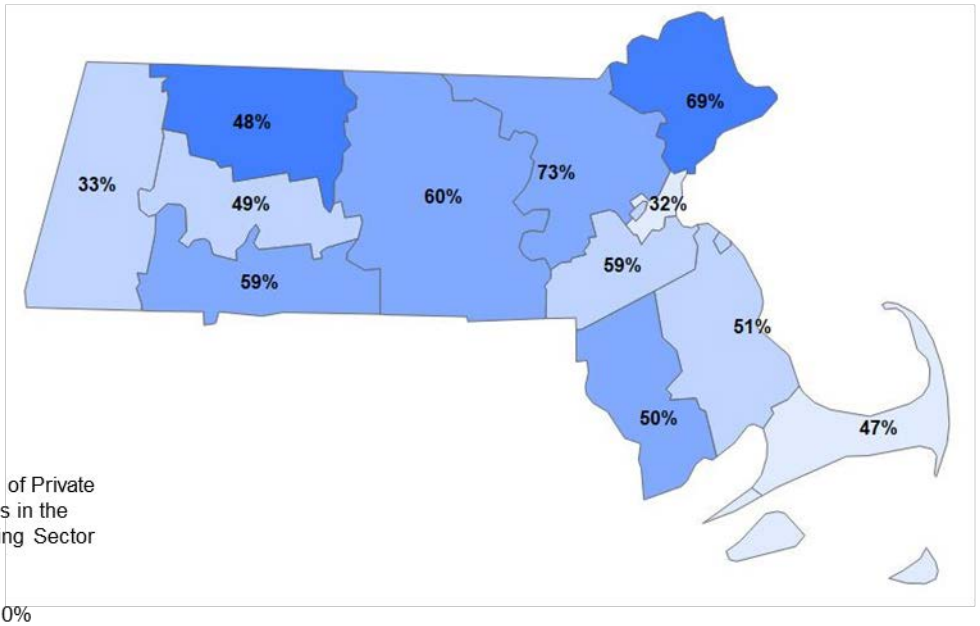
Source: US Census (2012), Bureau of Economic Analysis (2012), Bureau of Labor Statistics (2012), Deloitte Analysis

Snapshot of manufacturing in Massachusetts

As seen below, the map reveals that as a percentage of total county jobs, manufacturing is relatively evenly distributed across the Commonwealth, with strong pockets in Essex and Franklin Counties. Furthermore, the importance of advanced manufacturing is exhibited, as seven of the state's fourteen counties can count greater than 50% of manufacturing jobs as advanced.

Massachusetts Profile	
Population	6.6 million
Total Jobs	4.2 million
Total Manufacturing Jobs	263,705
Total Advanced Manufacturing Jobs	147,274

Percentage of County's Manufacturing Jobs that are classified as Advanced



Percentage of Private County Jobs in the Manufacturing Sector

- < 5%
- 5% - 10%
- 10% - 15%
- 15% - 20%
- 20% - 25%
- 25% - 30%

No data was available for the "Percentage of County's Manufacturing Jobs that are classified as Advanced" for Dukes County and Nantucket County.

No data was available for the "Percentage of Private County Jobs in the Manufacturing Sector" for Nantucket County.

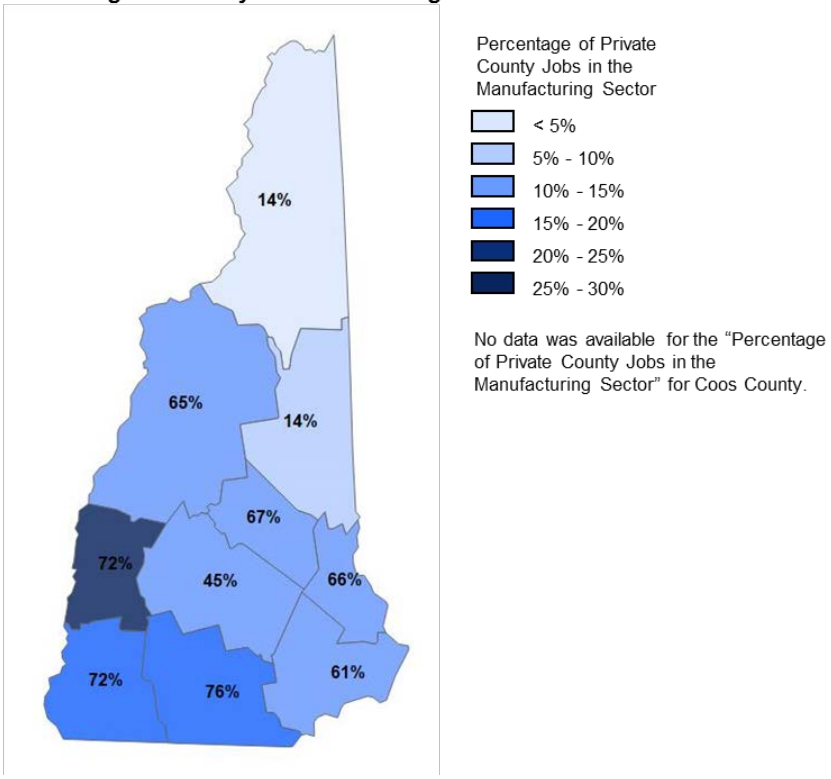
Source: US Census (2012), Bureau of Economic Analysis (2012), Bureau of Labor Statistics (2012), Deloitte Analysis

Snapshot of manufacturing in New Hampshire

Depicted below, the percentage of private county jobs in manufacturing is shown to increase as one moves across New Hampshire from north to south, with the notable exception of Sullivan County, in which just over 25% of all private jobs are in manufacturing. Additionally, the importance of advanced manufacturing is clearly on display with seven of the state's 10 county's having over 60% of all manufacturing jobs classify as advanced.

New Hampshire Profile	
Population	1.3 million
Total Jobs	825,524
Total Manufacturing Jobs	70,668
Total Advanced Manufacturing Jobs	45,619

Percentage of County's Manufacturing Jobs that are classified as Advanced



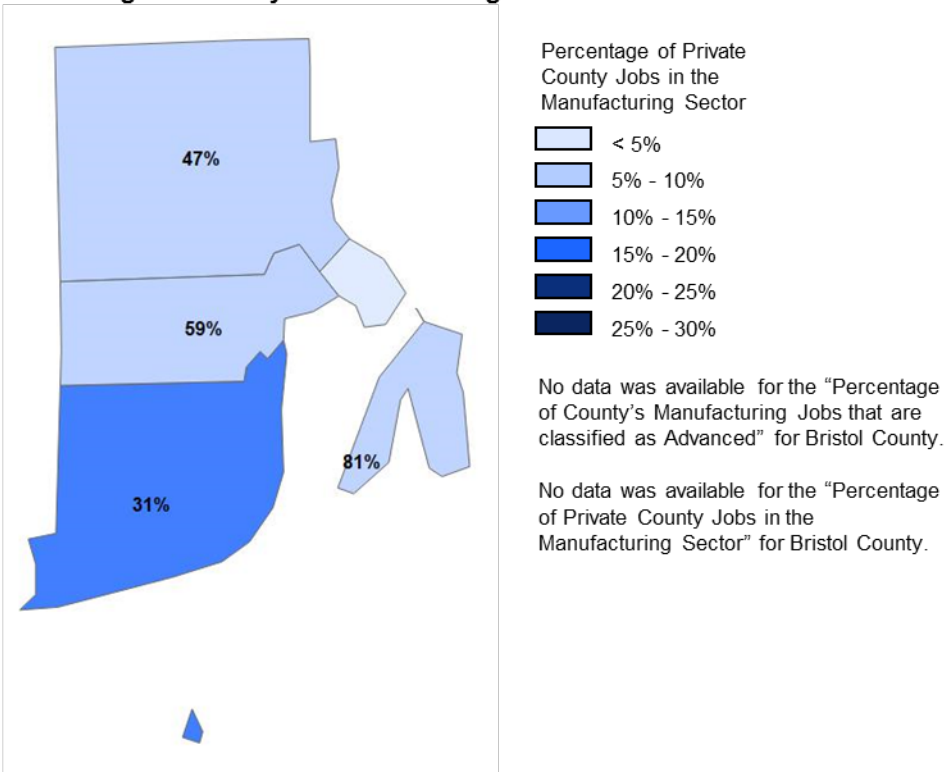
Source: US Census (2012), Bureau of Economic Analysis (2012), Bureau of Labor Statistics (2012), Deloitte Analysis

Snapshot of manufacturing in Rhode Island

Manufacturing jobs in the state of Rhode Island are relatively distributed, with Washington County as the only outlier with over 15% of all jobs in the sector. In terms of manufacturing jobs that can be categorized as advanced, Newport County far outpaces its neighbors with 81% of manufacturing jobs being advanced.

Rhode Island Profile	
Population	1.1 million
Total Jobs	588,336
Total Manufacturing Jobs	41,579
Total Advanced Manufacturing Jobs	19,146

Percentage of County's Manufacturing Jobs that are classified as Advanced



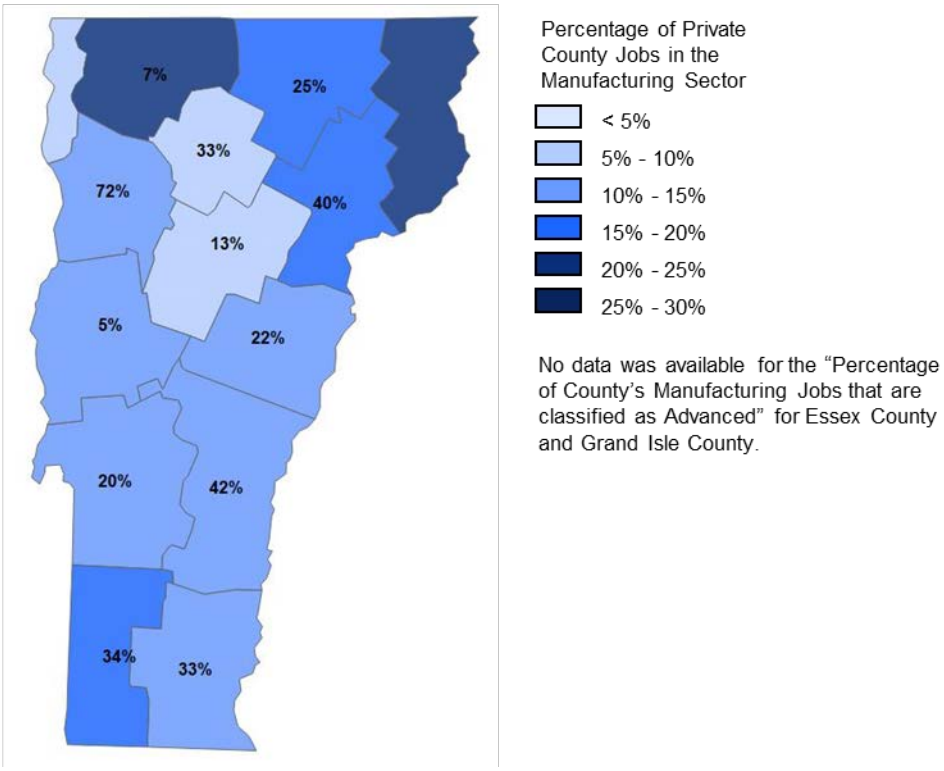
Source: US Census (2012), Bureau of Economic Analysis (2012), Bureau of Labor Statistics (2012), Deloitte Analysis

Snapshot of manufacturing in Vermont

Manufacturing is well represented across Vermont, and particularly so in the northern portion of the state, with Franklin, Orleans, Caledonia, and Essex Counties all having greater than 15% of their private sector employment in manufacturing industries. Advanced manufacturing is shown to be an important piece of the employment picture, as half of all Vermont counties have at least 25% of their manufacturing workforce employed in advanced subsectors.

Vermont Profile	
Population	625,953
Total Jobs	422,004
Total Manufacturing Jobs	35,573
Total Advanced Manufacturing Jobs	17,456

Percentage of County's Manufacturing Jobs that are classified as Advanced



Source: US Census (2012), Bureau of Economic Analysis (2012), Bureau of Labor Statistics (2012), Deloitte Analysis

Appendix B – Islands of Excellence

Throughout our research and interview process, we encountered a number of progressive and programs and initiatives – islands of excellence. The volume and variety of these programs speaks to the amount of excitement and activity in the advanced manufacturing realm. These islands of excellence are only some of the many examples that governments, industry players, and local groups are taking to move the industry forward.

Connecticut	NNMI Preparation: Improved regional collaboration	Comprehensive educational pathways	Workforce readiness	Industry partnerships & apprenticeships	Rebranding the industry: the Make It movement	Support to Scale (SMEs)	Policy & government alignment	Addressing the cost of doing business
Aerospace Components Manufacturers (ACM) Collaborative Model				✓		✓		
Connecticut Center for Advanced Technology	✓	✓	✓	✓		✓	✓	
CCOT High School Teacher Externship					✓			
Connecticut College of Technology Model		✓	✓	✓				
Connecticut Community College Apprenticeship Model		✓		✓				
CPath Program		✓	✓					
Dream It Do It					✓			
Goodwin College		✓	✓					
Manufacturing Innovation Fund	✓		✓			✓		

Maine	NNMI Preparation: Improved regional collaboration	Comprehensive educational pathways	Workforce readiness	Industry partnerships & apprenticeships	Rebranding the industry: the Make It movement	Support to Scale (SMEs)	Policy & government alignment	Addressing the cost of doing business
Maine Employer Focused Training Program			✓	✓				
Know Before You Go Legislation			✓					
Maine Apprenticeship Program				✓	✓			
MAMe - Virtual Consulting Firm	✓					✓		✓
Manufacturers Association of Maine - Manufacturing Summit	✓					✓		
Thornton Academy - Manufacturing Pilot Program		✓			✓			
York County Educational and Workforce Development Model		✓			✓			

Massachusetts	NNMI Preparation: Improved regional collaboration	Comprehensive educational pathways	Workforce readiness	Industry partnerships & apprenticeships	Rebranding the industry: the Make It movement	Support to Scale (SMEs)	Policy & government alignment	Addressing the cost of doing business
Advanced Manufacturing Collaborative	✓					✓	✓	
Blackstone Valley Technical High School & Waters Corp. Co-op program				✓	✓			
MACWIC		✓	✓		✓			
Mass Center for Advanced Design and Manufacturing	✓					✓	✓	
Northeastern University - Kostas Research Institute				✓				
Olin College - SCOPE Consulting Program			✓	✓				

Westfield State - STEM Building and Collaborative Center		✓	✓		✓			
Workforce Competitive Trust Fund	✓		✓	✓				
Workforce Training Fund			✓				✓	

New Hampshire	NNMI Preparation: Improved regional collaboration	Comprehensive educational pathways	Workforce readiness	Industry partnerships & apprenticeships	Rebranding the industry: the Make It movement	Support to Scale (SMEs)	Policy & government alignment	Addressing the cost of doing business
HydroTherm Machining and Tooling Training Program			✓	✓				
Keene State – Product Design and Computer Science Program		✓		✓				
Laconia High Schools Huot Technical Center		✓	✓	✓				
Markem-Imaje & Keene State Internship Program				✓				
New Hampshire Coalition for Business & Education	✓		✓				✓	
New Hampshire Manufacturing Week				✓	✓			
NH Community College Advanced Manufacturing Curriculum		✓	✓					
NH R&D Tax Credit						✓		✓
Regional Center for Advanced Manufacturing (RCAM)			✓	✓				
Whelen Engineering - Little League of Manufacturing				✓	✓			
Smiths Medical & Southern NH University Partnership		✓		✓				

Rhode Island	NNMI Preparation: Improved regional collaboration	Comprehensive educational pathways	Workforce readiness	Industry partnerships & apprenticeships	Rebranding the industry: the Make It movement	Support to Scale (SMEs)	Policy & government alignment	Addressing the cost of doing business
BrownConnect				✓				
Governor's Workforce Board - Subsidized Paid Internships				✓			✓	
Hope Global & Bryant University/URI Capstone Projects		✓	✓		✓			
Kleiner Perkins Engineering and Design Fellowships		✓		✓				
PRIME Program at Brown University		✓			✓			
RI Department of Labor Sector Initiative						✓	✓	
Skills USA			✓					

Vermont	NNMI Preparation: Improved regional collaboration	Comprehensive educational pathways	Workforce readiness	Industry partnerships & apprenticeships	Rebranding the industry: the Make It movement	Support to Scale (SMEs)	Policy & government alignment	Addressing the cost of doing business
Certified Manufacturing Technician Training Program		✓	✓					
Green Mountain Roasters - Employee Development Model			✓					
GSP School of Manufacturing Technology (GS Precision & Vermont Technical College)		✓		✓				
Mack Molding & VMEC High School Job Shadowing Program				✓	✓			
TechJam Vermont	✓			✓				
Vermont Employment Growth Incentive						✓	✓	

Vermont Flexible Pathways	✓	✓
Vermont HITEC	✓	✓
Vermont Strong Scholars Program		✓

Appendix C – Acknowledgements

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Appendix D – Notes

[I] Manufacturing jobs that are categorized as advanced manufacturing include: some primary metal manufacturing, fabricated metal product manufacturing, machinery manufacturing, computer and electronic product manufacturing, electrical equipment and appliance manufacturing, other transportation equipment manufacturing, some miscellaneous manufacturing, some chemical manufacturing, and some plastics and rubber products manufacturing.

[II] NB: Despite our attempts to replicate the 2009 methodology identically for the benefit of comparison, given changing data sources and formats over the time period examined, this task was not feasible for the 2015 study, and as such, one should note that the 2009 and 2015 analyses serve standalone data snapshots for their respective time frames and context and are not meaningful for comparative analysis.

[III] For value of shipments, data was not available beyond 2011 for purposes of analysis.

[IV] For the purposes of this study, the Great Recession is documented using the National Bureau for Economic Research (NBER) definition, which bookends the recession as occurring between December 2007 and June 2009. http://www.nber.org/cycles.html

[V] Statistics for Waco, Texas are used in this report to represent a "low-cost county" in the Southern U.S. with sufficient skills.

[VI] Estimated 70% cost does not include Maintenance & Operations (M&O) and/or services. The cost estimates provided are those to get a product "out the door."

[VII] This analysis does not include all the total cost of ownership such as transportation costs, intellectual property concerns, and other product life cycle costs, all of which would favor the United States.

[VIII] China has significant wage-rate inflation of 10 to 18% per year, according to many economic reports, which has slowed its growth.

[IX] Comparison between the ratios of concentration of a certain industry in a region as compared to that same ratio for a much larger geographical area, such as the entire nation, is commonly referred to as the location quotient, a measure of economic base analysis. A location quotient greater than 1 indicates that a region's economic strength in that sector or sub-sector is larger than average. 2012 data from the Bureau of Labor Statistics (BLS) was used to calculate location quotients for the New England states.

[X] Insufficient data available for Maine and Vermont tocalculate a location quotient for signal processing, navigation, optics, and measurement.

[XI] Insufficient data available for Vermont to calculate a location quotient for medical devices and biotechnology.

[XII] For additional insight into the application of AM in the area of tooling, see article by Mark Cotteleer, Mark Neier, and Jeff Crane, *3D Opportunity in Tooling: Additive Manufacturing Shapes the World*, Deloitte University Press, April 2014. http://dupress.com/articles/additive-manufacturing-3d-opportunity-in-tooling.

[XIII] The megapascal is a standard measure of pressure; 1 megapascal is equal to approximately 145 pounds per square inch. ASM International, "Technical spotlight: Additive manufacturing used to create first laser sintered cranial implant geometry," *Advanced Materials and Processes*, September 2012.

[XIV] Ibid.

[XV] Ibid.

[XVI] For more information on this topic, see Mark Cotteleer, Jonathan Holdowsky, and Monica Mahto, *The 3D opportunity primer: The basics of additive manufacturing*, Deloitte University Press, March 6, 2014, http://dupress.com/articles/the-3d-opportunity-primer-the-basics-of-additive-manufacturing/.

[XVII] For more information on the economics of additive manufacturing, see Mark Cotteleer, "3D opportunity for production: Additive manufacturing makes its (business) case," *Deloitte Review* 15, July 2014, http://dupress.com/articles/additive-manufacturing-business-case/.

[XVIII] For more information on this topic, see Cotteleer, Holdowsky, and Mahto, *The 3D opportunity primer*.

[XIX] The skills gap survey was conducted by Deloitte and the Manufacturing Institute during 2014 and involved a representative sample of 450 executives from companies of varying sizes and industries during this time.

[XX] Based on methodology in the Deloitte and Manufacturing Institute report, the following extrapolations have been made regarding the looming skills gap (job openings unfilled due to skills gap issue in advanced manufacturing over the time period 2015-2025):

- New England: 105,002 vacancies
- Connecticut: 28,453 vacancies
- Maine: 8,810 vacancies
- Massachusetts: 43,655 vacancies
- New Hampshire: 11,472 vacancies
- Rhode Island: 7,251 vacancies
- Vermont: 5,361 vacancies

[XXXI] Keene State works with Whalen Engineering (Charlestown), Sonnax (Bellows Falls), Hypotherm (Hannover), Hitchener Manufacturing (Milford), Markem-Imaje (Keene), Safran Aerospace (Rochester), Moore Nanotech (Swanzey), New Hampshire Ball Bearings (Peterborough), Smiths Medical (Keene), Maxxis International (not currently in NH).

[XXII] Each New England state has an established NIST Hollings Manufacturing Extension Partnership (MEP) affiliated center whose primary mission is to improve and grow manufacturing in their respective state, with an emphasis on SMEs. The MEP center model (a Federal initiative) is built upon public-private collaboration, including local industry, Federal, State, and education partnerships. MEP centers have strong local, regional and national ties and resources.

[XXIII] For more information on the Bayh-Dole Act, reference: http://www.gpo.gov/fdsys/pkg/CFR-2002-title37-vol1/content-detail.html.

[XXIV] US Energy Information Administration, Electric Power Detailed State Data – May 23, 2012 (the next update to this data source occurs January 2015).

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