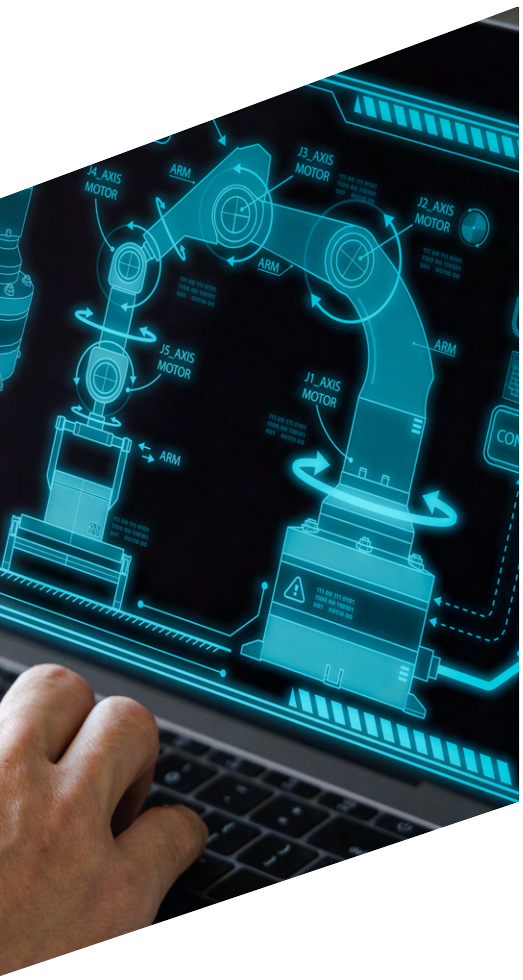
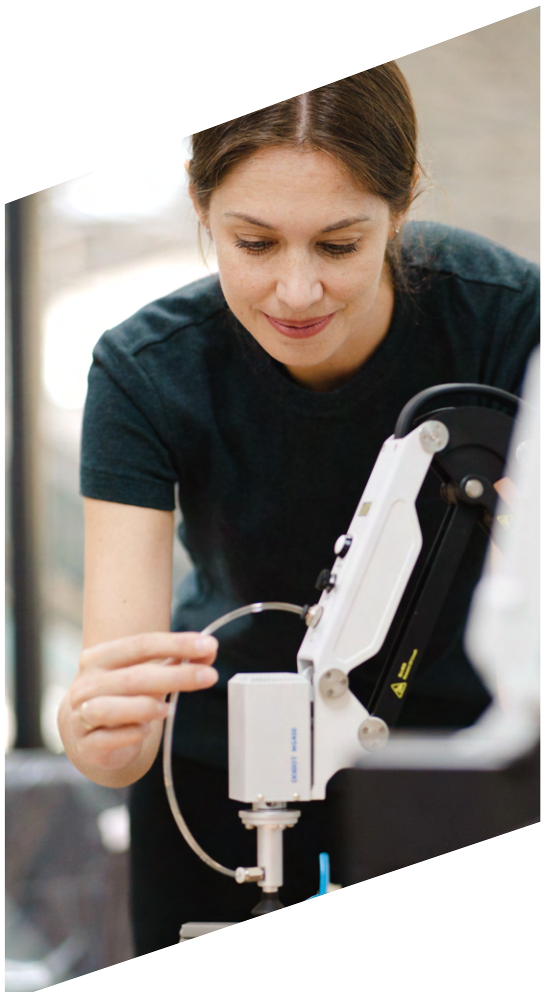
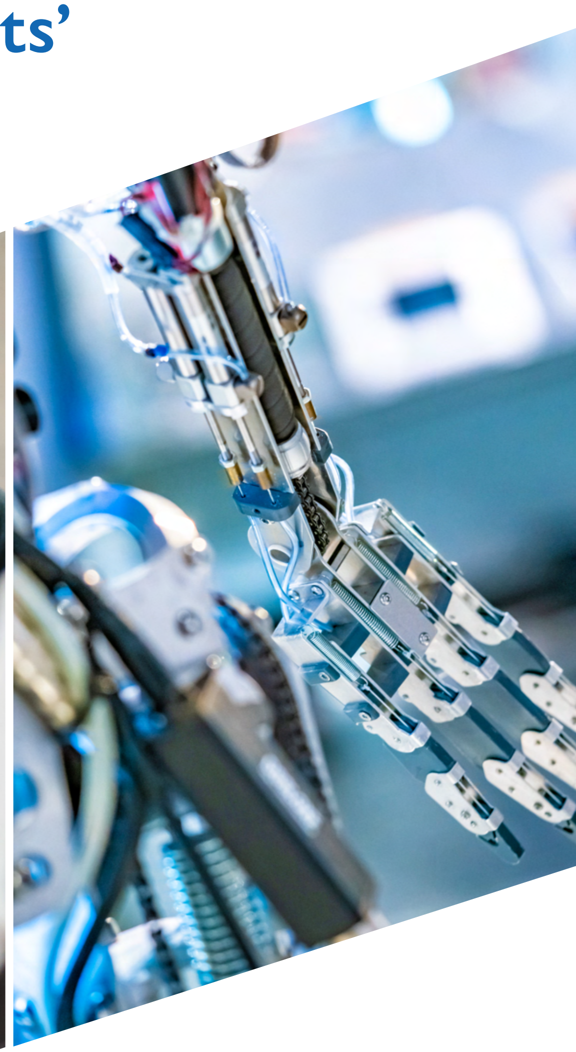
From INNOVATION to INTEGRATION

An Assessment of Massachusetts' Robotics Ecosystem







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Forward and Acknowledgements

This report was prepared by the Innovation Institute at the Massachusetts Technology Collaborative (MassTech) with data collection and research support from SRI International's Center for Innovation Strategy and Policy (SRI).

MassTech is a quasi-public agency within the Massachusetts Executive Office of Economic Development. MassTech's mission is to strengthen the competitiveness of the tech and innovation economy by driving:

- Strategic investments
- Partnerships, and
- Insights that harness the talent of Massachusetts.

The Innovation Institute is a division within MassTech formed in 2003 that implements a unique fact-based approach to economic development through collaborations with industry leaders, academic researchers, and policymakers to identify and support the growth of emerging technology sectors.

The Innovation Institute undertook this research report in consultation with SRI in late 2021 to assess the Massachusetts robotics industry cluster. Throughout 2022, the Innovation Institute staff and SRI collected quantitative and qualitative data on the state of the robotics ecosystem through extensive data analysis and interviews with members of the Massachusetts Robotics Industry Steering Committee (RISC). The RISC is a group of industry, academic, non-profit, and government robotics leaders convened by the Innovation Institute. Members of the committee help inform an action agenda for the short and long-term growth of the robotics industry in Massachusetts.

This report provides a set of 12 recommendations to grow the Massachusetts robotics ecosystem. The recommendations were originally drafted in 2022. Since then, the Innovation Institute has made progress on executing some of the recommendations stemming from a 2023 authorization from the Commonwealth of Massachusetts for $5 million in funding to strengthen conditions for growth within the robotics sector. The report will highlight areas where progress toward the recommendations has begun. Data collected in 2022 was updated for this publication in early 2024 by Innovation Institute staff.

In conducting this assessment, SRI and MassTech evaluated three core areas: robotics innovation, commercialization, and adoption – within the context of overarching workforce and regulatory factors. The report focuses on answering the following questions:

- What are the emerging opportunities in global, national, and technological trends on which the Massachusetts robotics community is uniquely positioned to capitalize upon?

- How can the Commonwealth of Massachusetts and robotics ecosystem stakeholders work together to advance the development, commercialization, and application of robotic systems in Massachusetts?

Authors

From Innovation to Integration: An Assessment of Massachusetts' Robotics Ecosystem was written by Megan Marszalek, Peter Haas, and Raagini Rameshwar, at MassTech's Innovation Institute with support from Christiana McFarland, Paul Liu, and Dylan Solden at the Center of Innovation Strategy & Policy at SRI International.

Thank you to the members of the Massachusetts Robotics Industry Steering Committee who contributed insights during the development of this report.

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Executive Summary

Robotics: An Enabling Technology with Potential for Transformative Impact across Massachusetts' Innovation Economy

Our simplest definition of a robot is a physical object that interacts with, moves through, and/or modifies its environment. When combined with technological advances in software, sensors, artificial intelligence, machine learning, batteries, and advanced materials, today's robots are increasingly capable of sensing their surroundings, navigating complex environments, carrying out computations to make decisions, and performing actions in the real world.

These capabilities have enabled the application of robotic systems beyond the early adopters of automotive manufacturers and warehouses. Robots capable of navigating complex environments and collaborating with humans will have exponential impact on productivity and unlock operational efficiencies for their human counterparts across a variety of sectors, particularly within healthcare, supply chain logistics, advanced manufacturing, agriculture, and public safety & defense.

According to McKinsey's assessment of industrial robotics, 88% of companies worldwide plan to increase investment in robotics and automation in their operations.[1] Advances in complementary technologies, labor shortages, geopolitical concerns, and moves toward environmental sustainability are contributing to the accelerated adoption of robotics to boost business competitiveness and resiliency.

The global market for robotics reached $59.7 billion in 2022 and is expected to grow 16.1% year over year to reach $200 billion by 2030. [2] This growth will be accompanied by powerful multiplier effects as productivity gains from increased adoption of robotic systems are realized. It is estimated that the wave of robotization expected through the decade will add an additional $4.9 trillion per year to the global economy.[3]

Regions with strong robotics clusters will hold a distinct competitive advantage in the global economy of the future. Massachusetts' robust innovation economy, driven by leading university R&D labs, a highly skilled workforce, and culture of entrepreneurship, is primed to capture a large portion of the economic benefits that accompany a booming robotics market. However, as global competition increases with many nations and regions actively vying to become the next "global hub for robotics," there is an urgent need for Massachusetts to fully capitalize on its concentration of unique innovation assets and make targeted investments to preserve and advance its leadership in robotics innovation, commercialization, adoption, and talent.

The Massachusetts Robotics Ecosystem

Massachusetts is home to more than 180 robotics companies. When viewed holistically to include related software and AI companies, manufacturers of core robotics components, and integrators of robotic systems, the cluster exceeds 400 companies.

Key players in the cluster include market leaders deploying the largest fleets of both consumer robots (iRobot) and logistics robots (Amazon Robotics). Boston Dynamics, one of the most recognizable robotics companies in the world, designs and develops their robotic dog (Spot), warehouse robot (Stretch) and humanoid robot (Atlas) in Massachusetts – all of which have been revolutionary in advancing the state of robot capabilities. The leading maker of collaborative robots (Universal Robotics) also has a presence in Massachusetts and is a subsidiary of Massachusetts-based Teradyne.

Over the last 15 years, Massachusetts has cemented its reputation as a hot bed for robotics innovation. There are more than 70 robotics R&D labs housed within Massachusetts' universities, non-profit facilities, and national labs and the Commonwealth produces the most robotics-related patents filed in the United States on a per capita basis.

Although Massachusetts' robotics R&D strength is unparalleled, there is a need for targeted interventions to 1) translate more foundational research from the lab to commercial applications, 2) integrate robotic systems into other sectors of the Massachusetts innovation economy, and 3) develop a diverse talent pipeline to train people capable of working with robots in both middle-skill and high-skill occupations.

As advancements in complementary technology usher in a new wave of intelligent robots, it is recommended Massachusetts take a strategic approach to grow the robotics cluster with focused emphasis on five core areas: innovation, commercialization, adoption, talent, and ecosystem development.

1. Innovation

Continued dominance in robotics innovation requires creating conditions for use-inspired interdisciplinary robotics R&D with applications across the Commonwealth's innovation sectors such as healthcare, advanced manufacturing, and defense. This includes ensuring R&D labs have necessary equipment and increasing opportunities for research institutions to collaborate with each other and the wider robotics community.

2. Commercialization

Increasing the success rate of robotics technology that makes its way into marketable products requires a strong network of entrepreneurial supports including mentors with experience growing companies to scale, access to seed and early-stage capital, and access to affordable test facilities to ensure efficiency, reliability, and safety of products. These initiatives will facilitate the progression of early-stage entrepreneurs, transitioning their products from preliminary research concepts to commercially viable offerings.

3. Adoption / Integration

As technological developments increase the use-cases for robotics across sectors, economies that encourage the adoption of robotics in industries of regional importance will reap exponential gains in productivity. Reducing barriers to adoption of robotics among small and medium sized enterprises (SMEs) through access to integration support, pilot programs, workforce training, and capital improvement funding can increase the competitiveness and resiliency of the Commonwealth's SMEs.

4. Workforce & Talent

As we see new robotic systems introduced in our daily lives for personal and professional use, it is essential that we train a workforce that can efficiently utilize these new technologies and provide equitable access to jobs in robotics fields. This includes increasing access to K-12 STEM and robotics programs, upskilling workers through robotics apprenticeships, and training engineers and scientists through robust secondary and graduate school programs.

5. Ecosystem Development

Accelerated growth of the robotics ecosystem in Massachusetts will require coordination among stakeholders within the cluster. Enhanced institutional capacity to orchestrate ecosystem activities can help increase visibility into opportunities and enable the facilitation of connections between complementary actors. It is this type of alignment and cooperation that will elevate the Massachusetts robotics industry from an emerging cluster to a mature and thriving ecosystem.

The robotics industry is at an inflection point with the convergence of rapid advancements in enabling technologies such as artificial intelligence and societal shifts that necessitate the increased adoption of robotics and automation. Massachusetts has the opportunity to capitalize on its position as a leading global robotics ecosystem through targeted investments that leverage the Commonwealth's unique assets to advance its competitive advantage in the industry while driving technological innovation, economic development, and job growth across multiple sectors.

Recommendations to Grow the Massachusetts Robotics Ecosystem

INNOVATION

1. Establish a **consortium of robotics-related university researchers** to work on collaborative research projects alongside industry experts
2. Continue to take a thought leadership role through **design and advocacy of robotics standards**

COMMERCIALIZATION

3. Increase access to more **early-stage funding**
4. Establish a **robotics hardware accelerator** to support Massachusetts robotics startups developing physical products
5. Increase access to **real-world and virtual test environments**

ADOPTION/INTEGRATION

6. Develop a strategy to **encourage the integration of robotics solutions across innovation sectors** including healthcare, advanced manufacturing, and defense
7. Become the first place DoD looks to source robotics & AI technology by supporting **commercialization of dual-use technologies**

WORKFORCE & TALENT

8. Engage industry partners to **scale project-based robotics education** in Massachusetts high schools
9. Establish **training programs for robotics technicians**

ECOSYSTEM DEVELOPMENT

10. Establish a **state-wide industry "concierge"** to facilitate connections within the ecosystem
11. Launch a unified **marketing campaign** to highlight the strengths and opportunities within Massachusetts' robotics ecosystem
12. Establish a **robotics innovation network** to connect the robotics community in Massachusetts and enable collaboration across institutions and disciplines

Trends Driving Robotics Growth

The global market for robotics reached $59.7 billion in 2022 and is expected to grow 16.1% year over year to reach $200 billion by 2030.[4]

The robotics market can be categorized in 2 segments: industrial robots and service robots. Industrial robots are largely used in manufacturing settings while service robots have applications in personal and professional settings. In 2022, worldwide industrial robot sales set a record, with over 553,000 units installed.[5] Of those units, installations within non-automotive sectors, such as electronics manufacturing, outpaced the automotive sector, emphasizing that the business case for robotics is extending to more industries. In 2022, worldwide sales of professional service robots grew by 48%. Robotics as a Service (RaaS) business models are enjoying popularity in this category with high adoption rates within the logistics and agriculture industries.[6] It is expected that service robots will outpace the adoption of conventional industrial robots to lead growth prospects for the industry as advances in enabling technologies expand robot use-cases.

Projected growth is largely driven by advances in technology that enable the integration of robots and robotic systems in a wide variety of industries. Companies are compelled to adopt new robotics technology to remain competitive and enhance operational resiliency in the face of labor shortages, geopolitical tensions, supply chain disruptions, and shifts in consumer behavior.

Technological Trends

Advances in Computer Vision

Increased computing power and advances in computer vision are enabling robots to identify, label, and process objects in the world around them. Advances in cameras and lidar sensors that can be embedded on mobile robots have greatly improved both the volume and quality of data collected. At the same time, more powerful computing infrastructure has enabled computer vision algorithms to work at scale. Computer vision allows robots to “see” and enables safer applications of robots in complex environments, such as warehouses and construction sites, as well as dynamic environments including city streets, sidewalks, and public spaces.

Advances in Artificial Intelligence

Rapidly developing breakthroughs in AI and machine learning are expanding robot capabilities. Techniques such as Large Language Models, Liquid Neural Networks, Hierarchical Graph Planners and Generative Adversarial Networks have advanced robot action planning, decision making and motion planning. This is allowing robots to make decisions and act based on what they “see” in the environment with computer vision and what they have “learned” in simulation and training with machine learning. Previously complex problems, such as room cleanup, are now within the realm of viability. Advanced 5G communications networks will enable these capabilities at scale and increase robot operational radius to further expand use-cases for robotic systems. This will mean more robots in unstructured environments and working safely in human environments in coming years.

Advances in Mobile Robots

One direct consequence of advances in artificial intelligence and computer vision is the rise of autonomous mobile robots (AMRs) – robots that can understand and move through their environments independently. AMRs represent the largest growth opportunity in robotics as they enable expanded use cases beyond their predecessors – autonomous guided vehicles (AGVs) that require a predefined path and operator oversight.

Applications of AMRs can unlock productivity gains in a variety of professional service sectors. For example, hospitals can use AMRs to support staff and transport medical supplies and farmers can use AMRs to monitor crops. The most prominent use case of AMRs to date has been in warehouse logistics where the global demand for goods and consumer expectations for fast shipping continue to drive demand for robotics and automation. The number of fulfillment sites with deployed AMRs is expected to reach over 53,000 by 2025, a significant jump from 9,000 at the end of 2020.[7] Moreover, nearly 75% of robots expected to ship in 2030 will be mobile.[8]

Greater Adoption of Collaborative Robots

Collaborative robots, or cobots, are designed to work closely with humans to enhance their productivity. Relative to larger industrial robotic systems that are often stationary and operate in cages away from humans due to safety concerns, cobots are increasingly mobile and work alongside human counterparts. Enhanced safety features such as collision detection and improvements in mobility control have enabled the increased adoption of collaborative robots.

Cobots offer greater flexibility for businesses, as they typically come at a lower cost than larger stationary systems and have a higher utilization capacity. Today's cobots are designed to be reprogrammable to accomplish a variety of tasks. These advantages are driving growth in the market for collaborative robots, valued at $475 million in 2020, and projected to reach $8 billion by 2030.[9]

Despite these projections, manufacturers still face technical and economic barriers to adoption of collaborative robots. The largest challenge cited by large and small manufacturers is the need for workers with programming skills who can set up and reprogram the cobots as they go about their tasks.[10]

Lack of Standardization Poses Adoption Challenges

There is a growing need for standards in the design and deployment of robotics hardware and software to ensure consistency, safety, interoperability, and compatibility across operations. This need is evident in global warehouses that gradually automate their operations in phases, leading to the use of equipment from multiple vendors within the same facility due to each phase's unique requirements and budget constraints. However, not all robotic systems possess the protocols and interfaces to communicate with each other on the warehouse floor, and the lack of robot standardization and interoperability has been a detriment to AMR adoption.

Standardization and robot interoperability are a long-term goal for the robotics industry. In 2021, MassRobotics established itself as a leader in this work by convening an AMR Interoperability Working Group along with industry leaders from Vecna Robotics, 6 River Systems, Locus Robotics, Seegrid, MiR, Autoguide Mobile Robots, Third Wave Automation, Open Robotics Foundation, and more to publish the world's first open-source interoperability standards for AMRs.[11] Shortly after, FedEx trialed the interoperability standards with several contributing robotics companies' AMRs, marking significant step toward standardization.

Societal Trends

E-commerce and shifts in consumer behavior

The pandemic accelerated the adoption of robotics technology, particularly within warehouses and fulfillment centers as stores raced to keep up with increased consumer demand. Amidst sustained popularity in digital sales, e-commerce companies are increasingly turning to micro-fulfillment centers located in urban areas equipped with autonomous robots. This trend toward smaller warehouses is expected to drive further growth in warehouse and logistics robots.

Labor shortages drive demand for automation solutions to complement human workers

The labor shortage in the United States, coupled with the experience of disrupted operations during the COVID-19 pandemic, have prompted more businesses to consider automation as both a short-term solution and a long-term resilience-building strategy. While robotics and automation are often viewed as threats that put jobs at risk, in reality, they pose opportunities to fill critical workforce gaps, free up workers for higher-level tasks, and allow businesses to remain competitive on the global stage, especially in a climate of aging labor forces.

Increasing elderly and disabled populations drive demand for assistive technology

By 2030, 21% of the US population will be over 65 and by 2060, the number of people 85 and older will triple from 2018 levels.[12] Robotics technology can be used to help aging populations age in place in the comfort of their homes while maintaining the quality of their lives and reducing caregiver burnout. Advancements in assistive robotics technology can enhance users' mobility and strength, provide transportation and social interaction, and aid in rehabilitation from illness or injury.

This phenomenon of using robotics to address an aging workforce is taking place in a number of industrialized nations. The South Korean government announced in December 2023 a joint public and private investment of 2.3 billion US dollars by 2030 into their robotics sector to address labor shortages brought on by demographic shifts. They will also train 15,000 workers in robotics by 2030.[13]

Geopolitical Trends

China's robotics sector is growing

Over the past two decades, China has invested heavily in robotics as part of a broader effort to modernize its manufacturing sector. China clearly recognizes robotics as a critical technology to its economic competitiveness, national security, and technological self-sufficiency. In December 2021, China published its second five-year plan to strengthen its robotics industry and achieve global robotics leadership. This strategy focuses on increased funding for core technology research in operating systems, perception capabilities, and deep integration of AI, 5G, big data, and cloud computing with robotics. China will strengthen its overall innovation capacity by establishing a national robot standardization organization and facilitating partnerships between companies at various tiers of the supply chain.[14]

U.S. Department of Defense is doubling down on robotics investment

The United States military is on a mission to put better, more reliable technology into the hands of soldiers faster than ever before. The U.S. Army's funding for military robot research and production was $17 million in 2015. In 2021, this funding increased to $379 million and supports 20 robotics R&D programs.[15] Additionally, procurement methods have been upgraded with streamlined procurement processes that encourage small businesses and startups to become DoD suppliers of emerging technology.

Robotic technologies hold the same appeal to militaries as they do for civilian markets—they increase human effectiveness and efficiency while being more robust and resilient in dangerous environments. Robots are used in military applications ranging from intelligence, surveillance and reconnaissance, search and rescue, combat support, and transportation. The military's robotics portfolio now includes unmanned aerial systems, unmanned underwater systems, ground robots, combat vehicles, logistics trucks, and soldier-borne exoskeletons – many of which incorporate technology and components with dual-use commercial applications.

The Massachusetts Robotics Ecosystem

Massachusetts' innovation economy, driven by university R&D, a highly skilled workforce, and culture of entrepreneurship has potential to be the premiere robotics ecosystem in the world. However, as global competition increases with many nations (e.g. Korea, Denmark, Switzerland, China, Singapore) actively vying to become the next global hub for robotics, there is an urgent need for Massachusetts to invest in its robotics sector to grow and retain top talent, attract private capital and advance the production and adoption of robotics technology.

SWOT Analysis

S

Strengths

- Critical mass of robotics companies with diverse range of applications spanning air, land, and sea
- High concentration of large robotics companies (iRobot, Amazon Robotics, Brooks Automation, Boston Dynamics, Toyota Research Institute)
- Record of successful public-private partnerships
- 1 in 4 robotics patents earned by MA investors
- Thought Leadership in robotics standards
- >70 robotics R&D labs

W

Weaknesses

- Lack of marketing strategy to promote the MA robotics cluster and attract companies
- Difficult to access test facilities and lack of real-world testing opportunities
- Insufficient sources of early-stage capital investing in robotics companies
- Lack of integration support for other industries looking to adopt robotics and automation

O

Opportunities

- Labor shortages intensify the need for automation to complement the workforce
- Growth in e-commerce and supply chain disruptions drive demand for warehouse robotics
- Infrastructure improvements and smart city initiatives with focus on sustainability
- Modernization of DoD with mandate for domestically sourced equipment
- Advances in sensors, AI, ML, batteries, and advanced materials expands robot capabilities
- Adoption of collaborative robots and improvement in human-robot interaction

T

Threats

- Competition among many nations and regions vying to become the global hub for robotics
- Talent shortage and skills gap, particularly for middle-skill technicians
- Other regions attracting MA-educated engineers and developers
- Reactionary regulations that stymie innovation and companies' ability to bring products to market
- Dependence on robots designed by foreign competitors presents national security concerns

The Commonwealth's strengths lie in innovation with cutting-edge R&D leading to technological breakthroughs. There is a strong base of highly skilled technical talent and a critical mass of robotics companies with a diverse range of applications spanning air, land, and sea. There is a strong presence of robotics companies specializing in warehouse & logistics robots, medical robots, assistive technologies, marine robots, and agricultural robots. As advancements in complementary technology usher in a new wave of intelligent robots, it is recommended that Massachusetts take a strategic approach to formalize institutional support to grow the robotics cluster. This approach emphasizes five core areas: innovation, commercialization, adoption, talent, and ecosystem development. The following sections each address one of these focus areas, highlighting the state of the Massachusetts ecosystem, comparisons to peer ecosystems, and recommendations for growth within each area.

INNOVATION

Massachusetts is a global leader in robotics R&D with a high concentration of university research labs and the highest level of robotics-related patents filed in the United States on a per capita basis.

Robotics R&D Labs

70+
Robotics R&D Labs in MA

Massachusetts is home to some of the world's most innovative research centers with researchers performing fundamental and applied robotics research across a wide variety of related disciplines. More than 70 labs across the state are housed at private and public universities, national laboratories, and private, non-profit R&D facilities. Interdisciplinary research is particularly strong in medical robotics and biometrics as researchers leverage the existing strengths in the Commonwealth's life sciences sector. Systems & controls within human-robot and robot-robot interaction is another research strength for the Commonwealth. In 2022-23, Massachusetts research institutions published 215 papers in IEEE journals, widely accepted as the worlds' leading source of impactful published research. California institutions published 397 papers, despite the much larger population, and Pennsylvania institutions published 120 papers.

Table 1: Representative Massachusetts Robotics Research Labs	
University Labs	
• Boston University • Harvard University • MIT • Northeastern University	• Tufts University • University of Massachusetts, Amherst • University of Massachusetts, Lowell • WPI
Private, Non-Profit R&D Facilities	
• Woods Hole Oceanographic Institute	• Draper Laboratory
Corporate R&D Facilities	
• Toyota Research Institute	• Boston Dynamics AI Institute
National Labs	
• MIT Lincoln Labs	• MITRE's National Security Engineering Center

Federal R&D

Massachusetts is a leading recipient of federal R&D funding. Massachusetts entities received $8.9 billion in federal R&D funding in 2020, which is equivalent to $2,160 for every employed worker in Massachusetts. On a per employed worker basis, this is 1.5x the federal R&D obligations to California and approximately 2.5x that of Pennsylvania.

While not all federal R&D funding received by Massachusetts goes to robotics research, the interdisciplinary nature of robotics enables the sector to benefit from research investments in secondary and even distantly related domains. As shown in Figure 2, most of Massachusetts's federal R&D awards come from the Department of Health and Human Services (HHS) and the Department of Defense (DOD), presenting opportunities for healthcare and military robotics applications.

Figure 1 | Federal R&D per Employed Worker, 2020

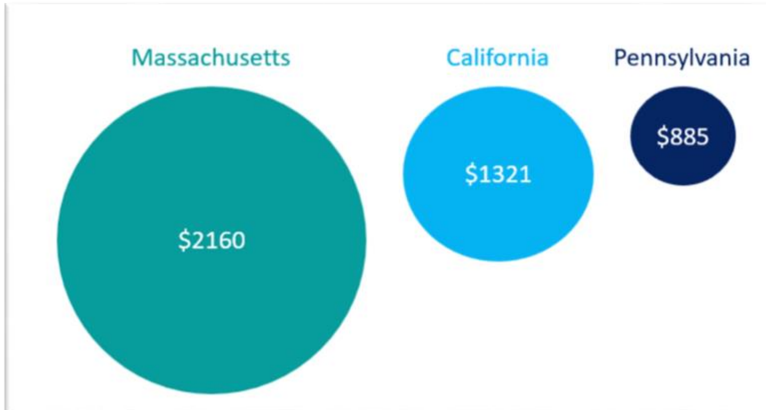
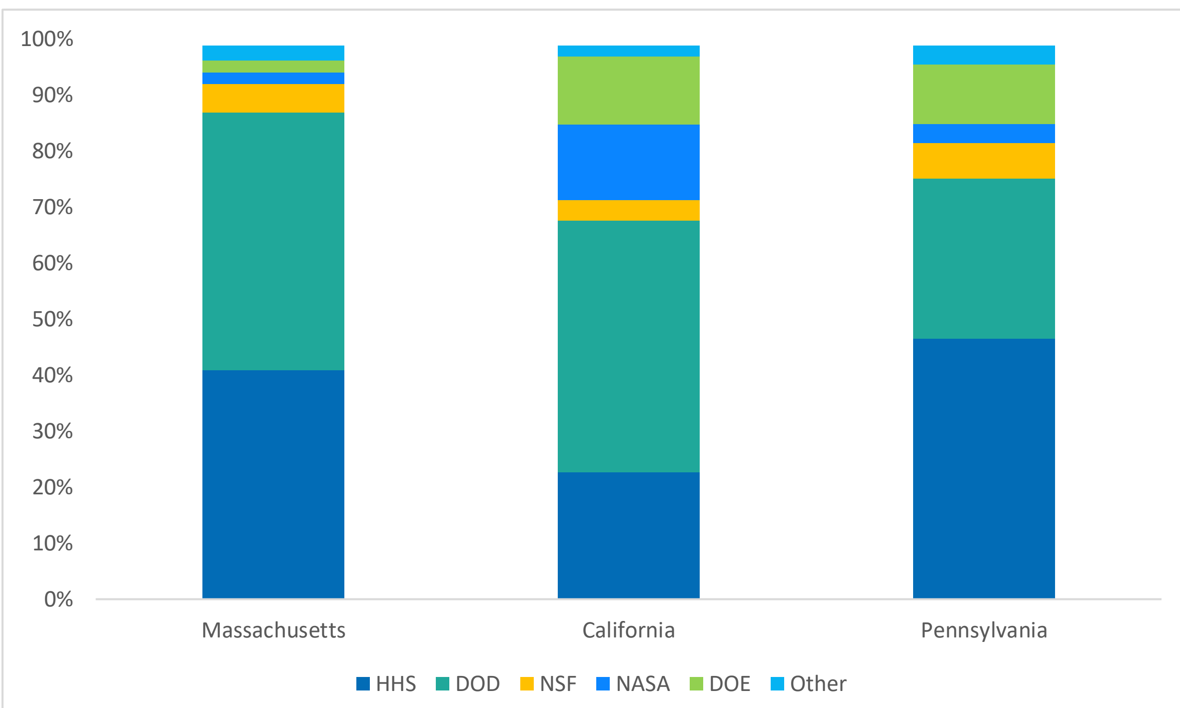


Figure 2 | Federal R&D by Funding Agency, FY21

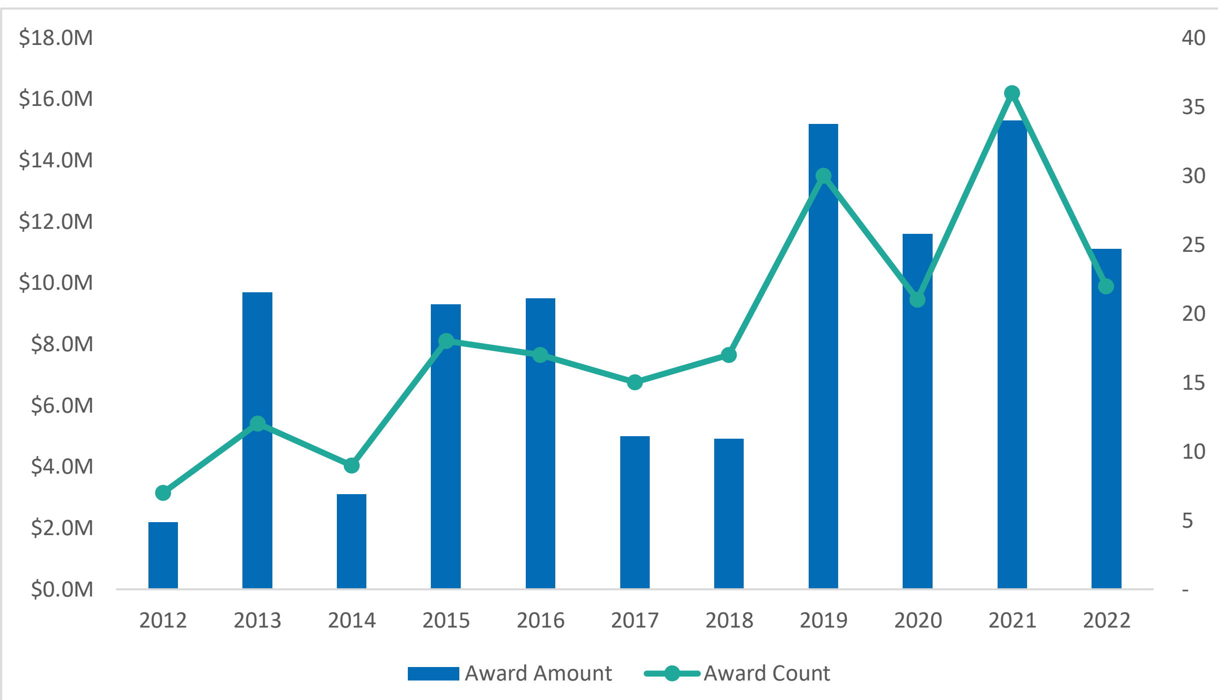


SBIR & STTR Awards

Federal funding for advancing science and technology is not limited to Massachusetts' R&D labs. Innovative small businesses are also attracting funding for their R&D efforts. The number of Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) awards granted to robotics companies in Massachusetts has generally been increasing over the past 10 years. In 2022, robotics companies in Massachusetts won 22 SBIR and STTR awards worth $11.17 million, capturing 9% of the U.S. total robotics-related award count and 8% of the U.S. total robotics-related award amount. By comparison, companies in California won 16% of the total award amount with 51 awards and Pennsylvania won 31% of the total award amount with 25 awards in 2022. Although California and Pennsylvania are larger states than Massachusetts, the fact that Massachusetts ranks third among them in SBIR/STTR awards in 2022 highlights an area for improvement within the Massachusetts robotics ecosystem.[16]

Massachusetts lags behind California and Pennsylvania in robotics SBIR/STTR awards

Figure 3 | Robotics SBIR/STTR Awards to MA companies (FY12 – FY22)



Robotics-Related Patents

1 in 4
Robotics-related patents granted to MA inventors

Over the last 15 years, Massachusetts has cemented its reputation as a hot bed for robotics innovation as the number of robotics patents awarded to inventors in the Commonwealth grew from 5 in 2006 to 143 patents in 2023. Notably, in 2023, nearly 1 in 4 robotics-related patents in the United States (and 1 in 12 worldwide) were granted to Massachusetts inventors. The Commonwealth also leads all states by a wide margin in patents generated per capita.

Figure 4 | MA Share of Robotics-Related Patents

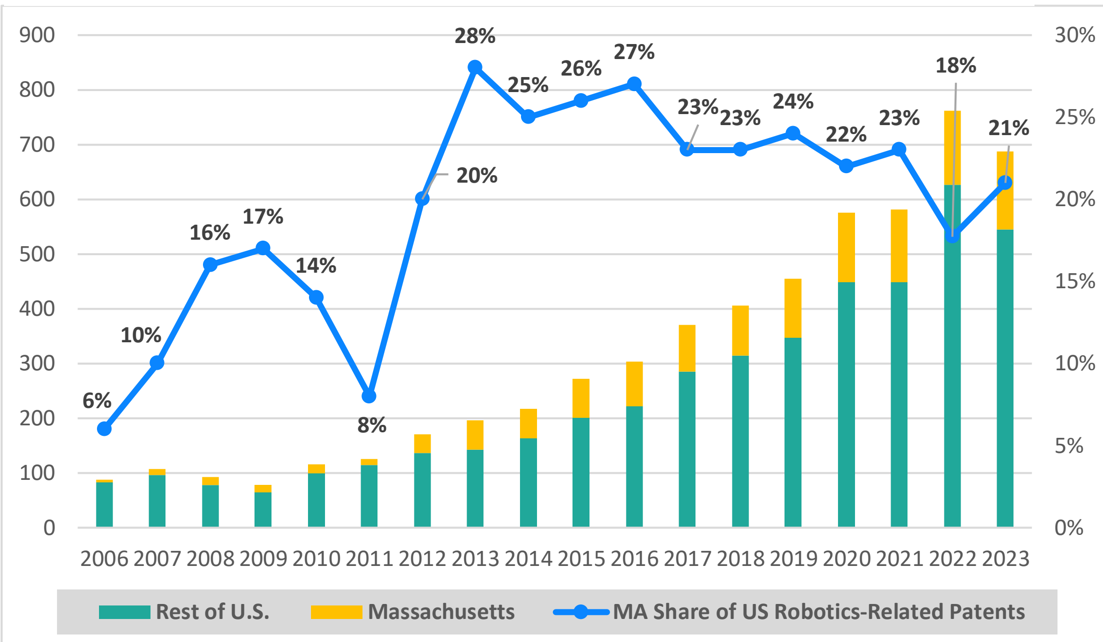


Table 2 | States Producing the Most Robotics Patents in 2022 and 2023

State	Patents 2022	Patents per 100k residents 2022	Patents 2023	Patents per 100k residents 2023
California	312	0.80	275	0.71
Massachusetts	135	1.93	143	2.04
Washington	52	0.67	50	0.64
Texas	29	0.10	37	0.12
Florida	31	0.14	32	0.14
Colorado	22	0.38	32	0.54
Michigan	33	0.33	31	0.31
New York	24	0.12	30	0.15
Pennsylvania	47	0.36	29	0.22

MA leads the nation in robotics patents on a per capita basis

Recommendations to Strengthen Robotics Innovation in Massachusetts

1. Establish a **consortium of robotics-related university researchers** to work on collaborative research projects alongside industry experts to engineer solutions to some of the world's greatest problems

The Massachusetts robotics sector has an opportunity to make its competitive advantage in robotics R&D even more compelling by harnessing the collective impact of its world-renowned researchers and roboticists through a connected consortium. In close partnership with industry, this network of interdisciplinary researchers could intensify work on use-inspired R&D projects with high degrees of commercial viability or applications for public good.

There are models for convening similar consortiums, such as the Wyss Institute for Biologically Inspired Engineering, in which the consortium encourages entrepreneurial endeavors or partnerships with industry that translate research into the market. A similar model for the robotics sector can improve the Commonwealth's ability to commercialize innovations stemming from basic and applied research and attract top tier research talent and robotics companies looking to outsource R&D.

2. Continue to take a thought leadership role through **design and advocacy of robotics standards**

Massachusetts researchers are well-recognized for their thought leadership on interdisciplinary robotics research that fosters novel applications of technology. Recently, industry leaders themselves have assumed a lead role in addressing one of the most pressing challenges within the industry – interoperability standards for the development and adoption of robotics systems capable of working together. In May 2021, MassRobotics' AMR Interoperability Working Group released a set of standards that allows organizations to deploy autonomous mobile robots (AMRs) and other automation equipment from multiple vendors to work together in the same environment. These standards provide a common framework for a variety of robots to interact with and understand each other on warehouse and factory floors.

Standardization of safety features and operating protocols can dramatically accelerate commercialization cycles and increase ease of use for end-users. Areas in which Massachusetts has a wealth of research talent and commercial experience, such as cybersecurity and human-robot interaction present practical opportunities to design additional robotics standards.

COMMERCIALIZATION

Massachusetts' dominance in robotics R&D and innovation does not translate fully to dominance in startup formation and commercial applications. Although Massachusetts is home to market-leading robotics firms in consumer robots and warehouse robots and has considerable strengths in medical robotics and enabling AI and software, the Commonwealth dramatically lags California in new formation of robotics businesses and attracting venture capital to support the growth of robotics startups.

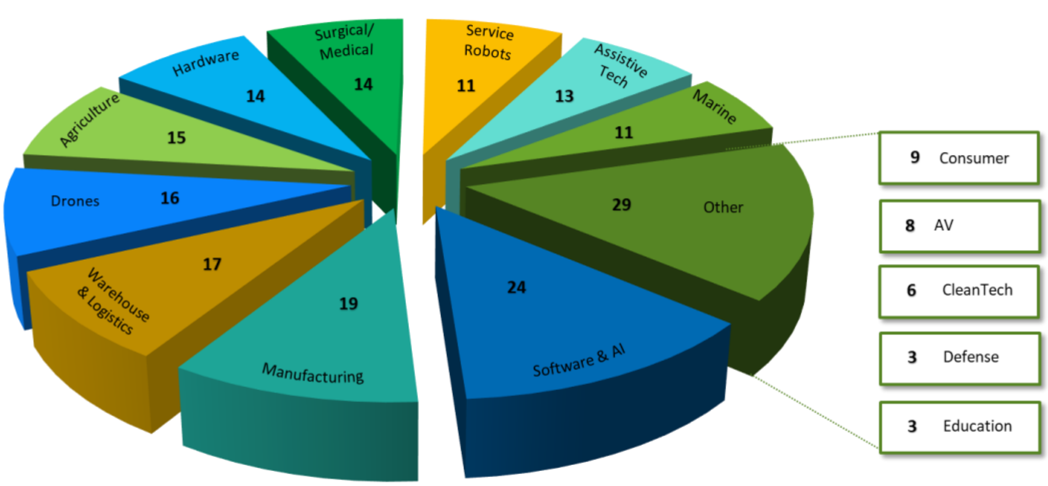
Industry Landscape

186
Massachusetts HQ robotics companies

One of the greatest assets of Massachusetts' robotics cluster is its large and diverse base of robotics firms, covering a range of technology segments that span air, land, and sea. The Commonwealth is home to at least 186 companies whose primary business is the production of robotics technology. When viewing the cluster holistically to include software and AI companies designing for robotic applications, manufacturers of core robot components, and integrators of robotic systems, the ecosystem expands to more than 400 companies.

The diversity of technological capabilities exhibited by the Commonwealth's robotics firms is shown in Figure 5. Unlike other robotics clusters in the United States, no technology segment dominates the landscape. There are 10 segments within the robotics industry with more than 10 companies operating in Massachusetts. The Commonwealth demonstrates considerable strengths in robotics AI, industrial manufacturing robots, and warehouse/logistics robots. Notably, there are growing segments of agricultural robots, surgical and medical robots, and assistive technology robots as well. Companies operating within the autonomous vehicle, clean tech, consumer robotics, education, and defense segments are also represented in the Massachusetts ecosystem, but with smaller clusters of less than 10 companies.   Given the interdisciplinary nature of robotics, many companies operate across multiple segments and were tagged for Figure 5 by their primary operating segment.

Figure 5 | MA Robotics Firms, by Segment



Market Leaders and Key Players

Massachusetts robotics firms include market leaders deploying the largest fleets of both consumer robots (iRobot) and logistics robots (Amazon Robotics). The leading maker of collaborative robots (Universal Robotics) has a presence in Massachusetts and is a subsidiary of Massachusetts-based Teradyne. Massachusetts is home to one of the first robotics unicorns (Locus Robotics) who reached a $1 Billion valuation with its warehouse AMRs in 2021 and achieved a major milestone of 2 billion units picked by its robots deployed in over 300 sites worldwide in August 2023.

iRobot Roomba vacuum

Amazon Robotics Kiva

Universal Robotics Cobot

Locus Robotics AMR

Other Massachusetts robotics companies that have been recognized as key players in the robotics industry at the forefront of innovation[17] include:

Boston Dynamics Spot & Atlas

Boston Dynamics

robots with human and animal-like dexterity able to move through difficult terrain for public safety and industrial inspection applications

Righthand Robotics RightPick System

Righthand Robotics

piece-picking solutions that improve performance and efficiency in order fulfillment and logistics

PFF Gita Cargo Robot

Piaggio Fast Forward

first-of-their-kind cargo-carrying following robots

ReWalk Personal 6.0

LifeWard

exoskeletons that aid in functional gait training for people who have lower limb disabilities

Vecna APT Autonomous Pallet Truck

Vecna Robotics

AMRs for logistics automation and work flow optimization

Bluefin 9

Bluefin Robotics

unmanned and autonomous underwater vehicles for defense, ship inspection, and ocean research applications

Myomo Myopro

Myomo

Assistive technology able to read nerve signals and activate small motors to facilitate natural arm and hand movement

American Robotics Scout System

American Robotics

first FAA-approved drone systems – allows customers to monitor, digitize and analyze assets in real-time

Startup Formation

The Massachusetts startup ecosystem, ranked sixth in the world by Startup Genome, is characterized by a dense cluster of life science companies and robotics companies.[18] A variety of highly regarded accelerators and incubators such as MassChallenge and Greentown Labs support the startup ecosystem, but the epicenter of the robotics startup community is MassRobotics.

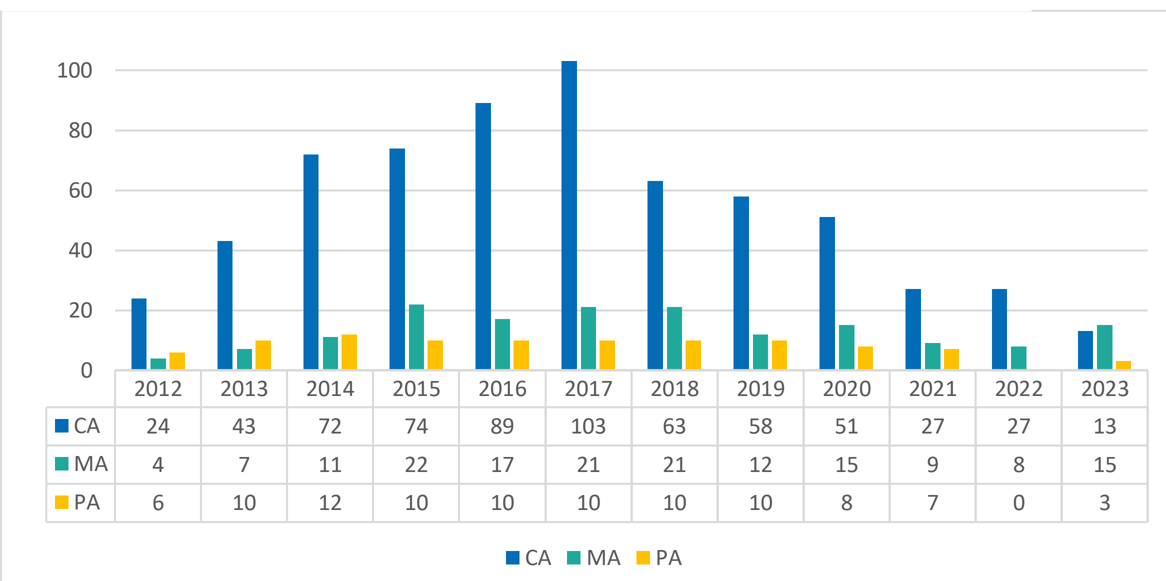
MassRobotics is the largest independent robotics hub dedicated to accelerating innovation and adoption in the field of robotics. MassRobotics prepares the next generation of successful robotics and connected device companies by providing robotics/automation startups with the workspace and resources needed to develop, prototype, test, and commercialize their products and solutions. Since MassRobotics opened in 2017, it has supported over 170 startups which have collectively hired over 600 employees and raised more than $550 million in capital. Notable companies that have grown out of MassRobotics include Realtime Robotics, Square Robot, American Robotics, Pison, Fringe AI, Activ Surgical, ORI, and Autonodyne.

4:1
California outpaces Massachusetts robotics startup formation by 4:1, on average

These success stories and the network built by MassRobotics are proof of a robust robotics startup community in the Commonwealth; nevertheless, Massachusetts historically lags California in startup formation as reported through Pitchbook data. In aggregate, California led firm formation with an average of 53.7 robotics companies formed each year since 2012. Comparatively, Massachusetts posted 13.5 new robotics companies on average per year since 2012. Although some of this disparity can be explained by sheer difference in population sizes, the authors of this report have flagged startup formation as a relative area of weakness that the Massachusetts robotics sector must strengthen to remain competitive.

Figure 6 further highlights the disparity in startup formation rates between Massachusetts and California. Notably, the gap has been closing over the last three years with Massachusetts actually surpassing California in the number of new robotics companies founded in 2023.

Figure 6 | Robotics Startup Formation Rates – CA, MA, PA (2012-2023)



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
CA	24	43	72	74	89	103	63	58	51	27	27	13
MA	4	7	11	22	17	21	21	12	15	9	8	15
PA	6	10	12	10	10	10	10	10	8	7	0	3

Robotics Test Facilities

Robotic startups often require extensive virtual and field testing to understand the capabilities of their prototypes and develop their products to achieve commercial viability. An assessment conducted by MassRobotics on behalf of the MassTech Collaborative in 2020 highlighted that Massachusetts is falling behind other states in supporting the testing needs of robotics companies.

The assessment looked at eight facilities that can be used to test new robotic technologies in Massachusetts. Few of these facilities are accessible to small-scale robotics entrepreneurs. Many test facilities are operated by academic institutions and often lack the institutional capacity to facilitate partnerships with small robotics companies for whom access to testing environments and equipment is critical to continued growth. For entrepreneurs, therefore, barriers to testing access are both institutional (facility access is contingent on passing a detailed vetting process or on becoming a member) and financial (users must pay for access to equipment, facilities, and services).

8
test facilities

There is also a growing need for simulated test environments where users can train and test artificial intelligence models on virtual robotic platforms. Robot-oriented AI algorithms such as Deep Reinforcement Learning require virtual spaces where robots can fail gracefully during training without risking physical hardware and putting people at risk. Establishing powerful and accessible virtual robot environments will allow robotics companies to train innovative models quickly and safely, decreasing their time-to-market and increasing the efficacy of their robotic platforms.

Massachusetts has an opportunity to retain and attract robotics talent by increasing accessibility to existing test facilities and developing new mixed-use facilities that can accommodate a variety of testing needs across simulated and real-world settings.

Table 3: Robotics Test Sites in Massachusetts

UMass Lowell New England Robotics Validation and Experimentation **NERVE Center**	The NERVE Center is an interdisciplinary robotics testing, research, and training facility with ability to test a robot's mobility, maneuvering, dexterity, sensor performance, navigation and obstacle avoidance capabilities.
Woods Hole Oceanographic Institute (WHOI) **Consortium for Marine Robotics**	WHOI supports specialized testing for marine robotics in underwater environments along with rapid prototyping and dock and dive support.
Northeastern University **Kosta Research Institute (KRI)**	KRI allows industry partners to rapidly assess and develop new drone technologies. The facility includes an outdoor netted area and a 50 x50x22' anechoic chamber for testing drones.
Joint Base Cape Cod	Joint Base Cape Cod is an FAA designated unmanned air systems technology test site set up inside the gates of the base.
Fort Devens	Devens is a former active-duty military base. An unused portion of the space may be rented to test self-driving vehicles and drone technology, although no formal process for renting space is available.
MIT Lincoln Laboratory Autonomous Systems Development Facility (ASDF)	Prototyping and testing of ground-based, aerial, and undersea autonomous systems on the Hanscom Air Force Base.
Worcester Polytechnic Institute (WPI) **Practice Point**	Health R&D and testing facility for designing, prototyping, and evaluating everything from rehabilitative devices to surgical robotics.
MITRE **BlueTech Lab**	The BlueTech Lab, located in Bedford, MA, is a 620,000-gallon tank for undersea testing and innovation. It was opened by MITRE as a national resource and can accommodate uncrewed undersea and surface vessels.

Venture Capital

$90B was invested in global robotics startups from 2018-2022, representing roughly 10% of overall VC investment in technology. The US, Europe, and Israel represent 70% of all robotics investment with Asia – particularly China - becoming a growing force in the market.[19]

California companies lead the United States in attracting robotics venture capital by a wide margin. As shown in Table 4, Massachusetts attracted 10% of all US robotics venture capital in 2022, compared to California's 54%. 2023 saw a widening of this trend with Massachusetts attracting 3% and California attracting 68% of robotics venture capital investment in the United States.

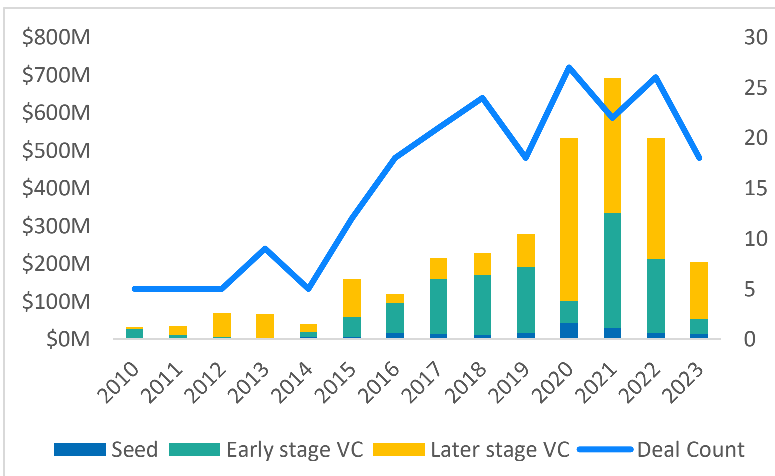
Table 4: VC raised by robotics companies in 2022 and 2023 – peer state comparison

	2022				2023			
Deal Type	**MA**	**CA**	**PA**	**US**	**MA**	**CA**	**PA**	**US**
Seed	$15.3M	$188.7M	$16.8M	$356.90M	$14.9M	$133.2M	$11.0M	$304.41M
Early stage VC	$196.3M	$831.6M	$40.0M	$1.52B	$38.8M	$416.7M	$30.9M	$738.44M
Later stage VC	$320.1M	$2.0B	$207.8M	$3.66B	$148.6M	$3.7B	$245.1M	$5.23B
Total ($) Robotics	$531.6M	$3.0B	$264.6M	$5.5B	$202.3M	$4.3B	$286.9M	$6.27B
% U.S. Robotics VC	10%	54%	5%		3%	68%	5%	
% U.S. Total VC	9%	35%	2%		3%	72%	0%	

Massachusetts Robotics Capital Investment Trends

Robotics VC funding in Massachusetts from 2016 to 2019 was driven by early-stage funding, which coincides with a general increase in robotics startup formation during those years. The last four years of 2020 through 2023 were characterized by large, later-stage investments to several fast-growing companies. The largest deals over this time period included a $263M Series B2 investment to Berkshire Grey in 2020 and a $150M Series E investment to Locus Robotics resulting in Massachusetts' first robotics unicorn with a valuation of $1B. Locus followed up with a $117M Seres F in 2023 with a post-deal valuation of $2B.

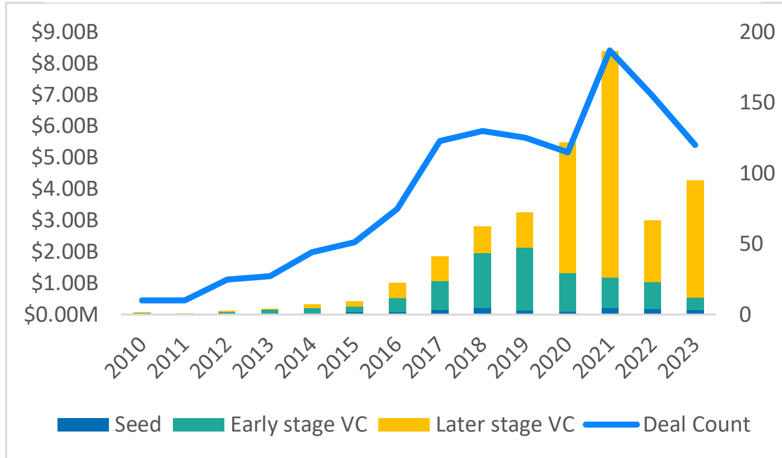
Figure 7 | MA Robotics VC Investment, (2010-2023)



California Robotics Capital Investment Trends

Venture capital data for California robotics companies reveals the same trend in the share of early-stage and later-stage funding as the Massachusetts data. Early-stage companies saw most of the investment dollars from 2016 through 2019 with later-stage deals characterizing the past four years. This is most pronounced in 2020 and 2021 when Waymo raised a $3B late-stage Series A in 2020 followed by a $2.5B Series B in 2021.

Figure 8 | CA Robotics VC Investment, (2010-2023)

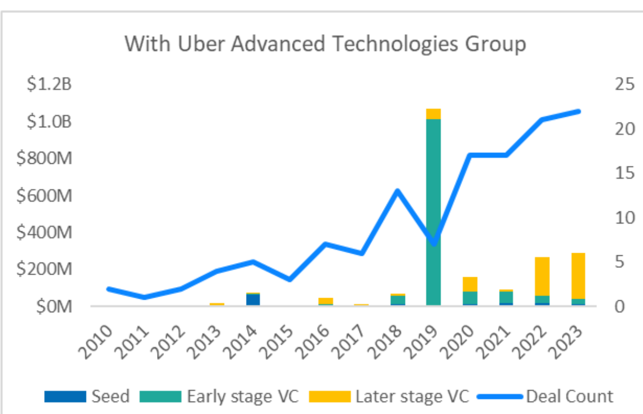


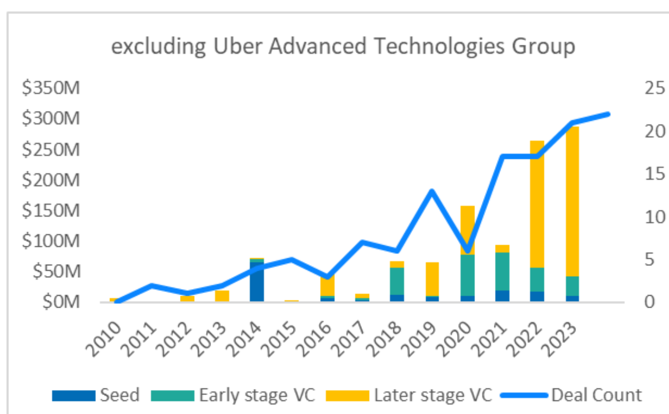
Pennsylvania Robotics Capital Investment Trends

Venture capital trends within the Pennsylvania ecosystem look a bit different than Massachusetts and California. The ecosystem was in the nascent stages of development in 2016-2019 and did not demonstrate the same level of early-stage investment as its peers. The first major investment into the ecosystem came in 2019 with a $1B early-stage investment to Uber Advanced Technologies Group. This arm of Uber was based in Pittsburg and working on developing self-driving cars and trucks before it was acquired by New York-based Aurora in 2020. Figure 9 shows the robotics VC trends for Pennsylvania with and without the Uber ATG deal.

Later-stage deals characterized 2022 and 2023 in the Pennsylvania robotics ecosystem. Agility Robotics secured a $150M Series B in 2022 and Gecko Robotics secured a $173M Series C investment in 2023.

Figure 9 | PA Robotics VC Investment, (2010-2023)





Investment Trends Across Robotics Verticals

Figure 10 displays the industry segments attracting the highest levels of investment in the Massachusetts, California, and Pennsylvania robotics ecosystems since 2020.

Figure 10 | Leading Industry Vertical Attracting Robotics VC Investment Since 2020

Massachusetts	
AI & Machine Learning	19%
Supply Chain Tech	15%
Mobility Tech	10%
Manufacturing	8%
Autonomous Cars	6%
TMT*	5%

California	
AI & Machine Learning	23%
Mobility Tech	16%
Autonomous Cars	15%
TMT*	5%
Big Data	5%
Supply Chain Tech	4%

Pennsylvania	
Industrials	16%
AI & Machine Learning	15%
Manufacturing	11%
Supply Chain Tech	9%
TMT*	8%
AgTech	4%

* *Technology, Media, & Telecommunications*

The high share of capital deployed to AI and Machine Learning applications within robotics across all three ecosystems is indicative of the close relationship and interdependencies of AI and robotics. Capital deployed to Massachusetts highlights the Commonwealth's strengths in AI, warehouse & logistics robots (supply chain tech) and industrial robotics (manufacturing). Pennsylvania also demonstrates strengths in industrial robots with the industrials vertical and manufacturing vertical both attracting a significant share of investment. The presence of the ARM Institute – the federally funded Manufacturing USA Institute for Advanced Robotics in Manufacturing – in Pittsburgh is a leading driver of advancements in the industrial and manufacturing robotics vertical in Pennsylvania. California's strengths lie within the autonomous vehicle and mobility tech industry verticals. This partially explains the dramatically higher amounts of capital invested in the California robotics ecosystem since AV companies require significant capital costs.

Overall, the distribution of capital has largely been awarded to companies that have been successful in developing robotic solutions for early-adopting industries with industrial and logistics applications. As the use-cases for robotics expands with impact on efficiency and productivity across more sectors, it is likely that the distribution of capital will become more diverse across industry verticals. We already see AgTech cracking the top six in Pennsylvania and can expect similar gains throughout the entire robotics market with robotics companies creating solutions for HealthTech, CleanTech, FoodTech, and more.

Exits – IPOs and Mergers & Acquisitions

A common complaint among venture capitalists is that robotics is not an attractive market for investment because there are too few successful exists and hardware businesses are too hard to scale. While it is true that scaling a hardware company is inherently more difficult than software, it is becoming less challenging as 3D printing shortens production cycles and reduces costs for hardware producers. Robotics companies can also find ways around developing their own hardware, instead creating value by optimizing AI and ML to solve specific industry pain points with off-the-shelf hardware.

It is undeniable that there are not many successful exits to point to in the robotics market. There are currently 16 publicly traded US-based robotics companies listed on the major US stock exchanges (listed in table 5), excluding companies primarily operating in the autonomous vehicle space. Massachusetts is home to three of these publicly traded companies – Symbotic, iRobot, and Microbot Medical. California is also represented by 3 companies, while Pennsylvania does not have any publicly traded robotics companies.

Table 5: Publicly Traded US Robotics Companies on US Stock Exchanges

Company	State	Listing Date	Listing Type	Market Cap *(as of 2/22/24)*	Segment
UiPath (NYS: PATH)	NY	April 2021	IPO	$13.26B	Software
Symbotic (NAS: SYM)	MA	June 2022	SPAC	$3.53B	Warehouse Robots
AeroVironment (NAS: AVAV)	VA	Jan. 2007	IPO	$3.48B	Defense
iRobot (NAS:IRBT)	MA	Nov. 2005	IPO	$333.55M	Consumer Robots
Intuitive Machines (NAS: LUNR)	TX	Feb. 2023	SPAC	$241.97M	Aerospace
Ouster (NYS: OUST)	CA	March 2021	SPAC	$221.77M	LiDar Systems
Richtech Robotics (NAS: RR)	NV	Nov. 2023	IPO	$97.21M	Service Robots
Monogram (NAS:MGRM)	NY	May 2023	IPO	$95.26M	Medical Robots
Red Cat Holdings (NAS: RCAT)	PR	April 2021	2PO	$52.66M	Defense
Knightscope (NAS: KSCP)	CA	Jan. 2022	IPO	$42.49M	Security Robots
Ekso Bionics Holdings (NAS: EKSO)	CA	August 2016	2PO	$34.21M	Exoskeletons
Multisensor AI Holdings (NAS: MSAI)	TX	Dec. 2023	SPAC	$33.36M	Manufacturing
Microbot Medical (NAS: MBOT)	MA	Nov. 2016	SPAC	$18.26M	Medical Robots
Sarcos Tech. and Robotics (NAS: STRC)	UT	Sept. 2021	SPAC	$14.5M	Exoskeletons
Nauticus Robotics (NAS: KITT)	TX	Sept. 2022	SPAC	$13.99M	Marine Robots
Sidus Space (NAS: SIDU)	FL	Dec. 2021	IPO	$11.66M	Aerospace

Mergers & Acquisitions (M&A) has generally been a more productive option for robotics company exit strategies. There were 316 completed robotics M&A deals in the US between 2012-2023. 32 Massachusetts-based robotics companies completed mergers or acquisitions during this period. Table 6 lists the Massachusetts robotics M&A deals with disclosed values of more than $50M.

MA world-leading strengths in warehouse & logistics robotics is evident in the state's M&A activity. Amazon, Walmart, and Shopify all turned to Massachusetts companies to vertically integrate warehouse robotics into their operations. Amazon acquired Kiva Systems to become Amazon Robotics in 2012. Shopify acquired Waltham-based 6 River Systems in 2019. Walmart acquired Andover-based Alert Innovation to become Walmart Advanced Systems & Robotics in 2022. Another major player in the warehouse robotics space, Berkshire Gray was taken private by SoftBank in 2023.

Table 6: M&A Deals >$50M - MA Robotics Companies (2012 - 2023)

Company	Acquisition Value	Date	Acquirer	Segment
Corindus Vascular Robots	$1.1B	October 2019	Siemens Healthineers	Medical Robots
Boston Dynamics	$880M	June 2021	Hyundai Motors Group	Logistics/Other
Amazon Robotics (formerly Kiva Systems)	$678M	August 2012	Amazon	Warehouse/Logistics
nuTonomy	$454M	November 2017	APTIV	AV Software
Alert Innovation	$400M	November 2022	Walmart	Warehouse/Logistics
6 River Systems	$394M	October 2019	Shopify	Warehouse/Logistics
Endeavor Robotics (formerly iRobot Defense & Security	$385M	March 2019	FLIR Systems	Defense
Berkshire Grey	$375M	July 2023	SoftBank	Warehouse/Logistics
Hydroid	$350M	March 2020	HII Technical Solution	Marine Robots
Ocean Server Technology	$118M	March 2017	L3 Technologies	Marine/Defense
AutoGuide	$81.74M	November 2019	Teradyne	Warehouse/Logistics
American Robotics	$69.31M	August 2021	Ondas Networks	Drones
Root AI	$59.11M	April 2021	AppHarvest	Agriculture
Spyce	$50.69M	September 2021	Sweetgreen	FoodTech

Overall, M&A became an attractive strategy across most tech sectors as IPOs slowed in 2021-2023. However, increased SEC regulations and FTC scrutiny pose challenges to this exit option. iRobot and Amazon Robotics ran into this challenge when they agreed to a $1.7B deal for Amazon to acquire iRobot in August 2022. The deal was intended to deepen Amazon's presence in consumer robots to complement their logistics robot portfolio, but the deal was cancelled in January 2024 after the European Union refused regulatory approval.

Recommendations to Accelerate Commercialization of Robotics Technology in Massachusetts

It is expected that a cluster boasting 70+ robotics R&D labs and the highest per capita rate of robotics patents would attract higher levels of early-stage funding necessary to sustain its position as one of the top robotics clusters in the world. The following recommendations will help bridge the gap between foundational research and the translation of innovations to market.

1. Increase access to more **early-stage funding sources**

Research and capital-intensive robotics companies struggle to attract financing without proof of revenue or tangible assets. Founders of robotics companies repeatedly expressed that the most helpful source of early-stage support is the opportunity for seed capital to fuel costly R&D and testing necessary to bring new technologies to market. Seed funding provides emerging technology companies with necessary capital to grow an idea and generate traction to the point where they can attract additional external funding.

2. Establish a **robotics hardware accelerator** to support MA robotics startups developing physical products

Massachusetts is home to a variety of startup support organizations offering incubation and acceleration programs with sector-agnostic and industry-specific focuses. There are dedicated accelerators in other innovation sectors such as health tech and fintech, but not robotics. There is a need for a dedicated accelerator program to help robotics hardware companies overcome barriers to commercialization through access to equipment and test facilities, connections with local manufacturers and suppliers, and mentorship from executives with experience growing robotics companies to scale or within targeted application markets.

PROGRESS UPDATE → MassTech and MassRobotics created the MassRobotics Accelerator in the Fall of 2023. The 3-month program kicked-off in February 2024 with a cohort of 10 startups commercializing robotics hardware solutions. 140 companies representing 25 countries applied for the program. Of the 10 selected, 7 companies are currently headquartered in Massachusetts and the other 3 have committed to establishing operations in the Commonwealth. The accelerator will culminate with a demo day for investors during the Robotics Expo & Summit held in Boston in May 2024. MassTech is funding the management of the program as well as providing $100,000 non-dilutive grants to each company.

3. Increase access to **virtual and real-world test environments**

Mutually beneficial collaborations among governments, public and private institutions, and industry could enhance both virtual and real-world test environments for robotics, promoting safe and effective adoption. Co-designed pilot programs could showcase robotic applications in public domains, addressing challenges like public safety and infrastructure maintenance. Simultaneously, the development of accessible simulated environments would allow for the safe training of robot-oriented AI, leveraging advanced algorithms for quicker, risk-free training. This dual approach could improve public perception, expedite innovation, and ensure the integration of robotics into daily life and work more seamlessly. Additionally, leveraging virtual platforms as educational tools can revolutionize how young students learn robot programming, making complex concepts more accessible from an early age.

ADOPTION/INTEGRATION

Robotics as an enabling technology is capable of unlocking process improvements and productivity gains across a wide variety of industries in the Commonwealth's economy including advanced manufacturing, healthcare, agriculture, and defense. Robotics also presents opportunities to enhance our quality of living with applications that improve healthcare services, increase mobility and self-sufficiency for disabled and elderly populations, reduce the time we spend on household chores, and make shopping and delivery more efficient, among other benefits. To date, only a small percentage of early adopters have integrated robotics in their operations and daily lives, but technological advancements in robot capabilities and societal trends related to labor shortages and aging populations will drive greater utilization of robotics that improve the way we work and live.

Robot Utilization across Countries

It is difficult to measure the level of robot utilization at the state level, but country-level data can be used to illustrate trends in robot adoption gauged by robot density which measures the number of robots per 10,000 workers in the manufacturing industry. According to the IFR (International Federation of Robotics), global average robot density grew 5% in 2022, setting a new record high. The top 10 most automated countries shown in Figure 11 are South Korea (1), Singapore (2), Germany (3), Japan (4), China (5), Sweden (6), Hong Kong (7), Switzerland (8), Taiwan (9), and USA (10). The electronics industry became the primary customer for industrial robots in 2020 and has maintained that position since then, with the automotive industry in second place.

In 2019, China ranked 15th in robot density, but significant installations of industrial robots through 2022 accelerated China's position to the 5th country in robot utilization, dramatically outpacing installations in other countries. As highlighted in Figure 12, more than 290,000 new units of industrial robots were installed in China in 2022 compared to 50,400 and 39,600 units installed in Japan and the US, respectively.[20]

Figure 11 | Robot Density, 2022

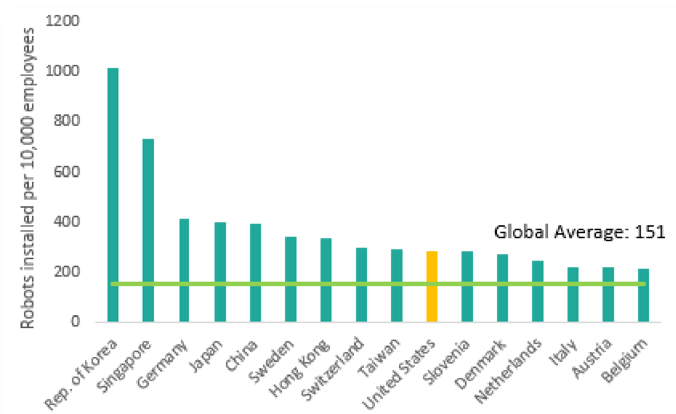
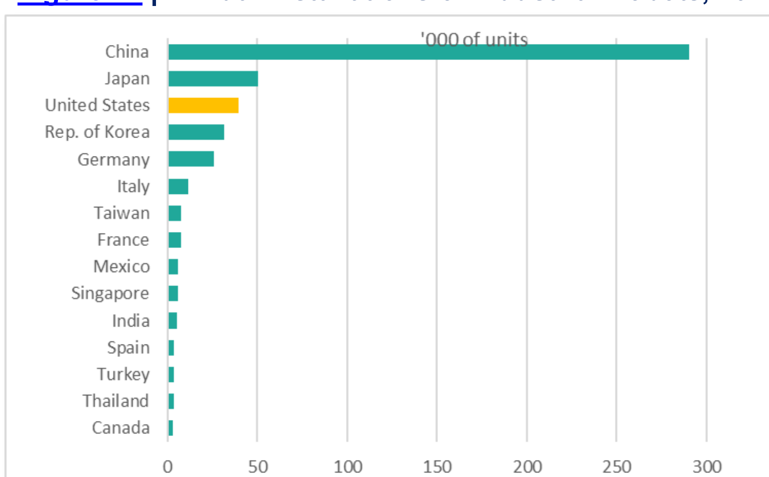


Figure 12 | Annual Installations of Industrial Robots, 2022

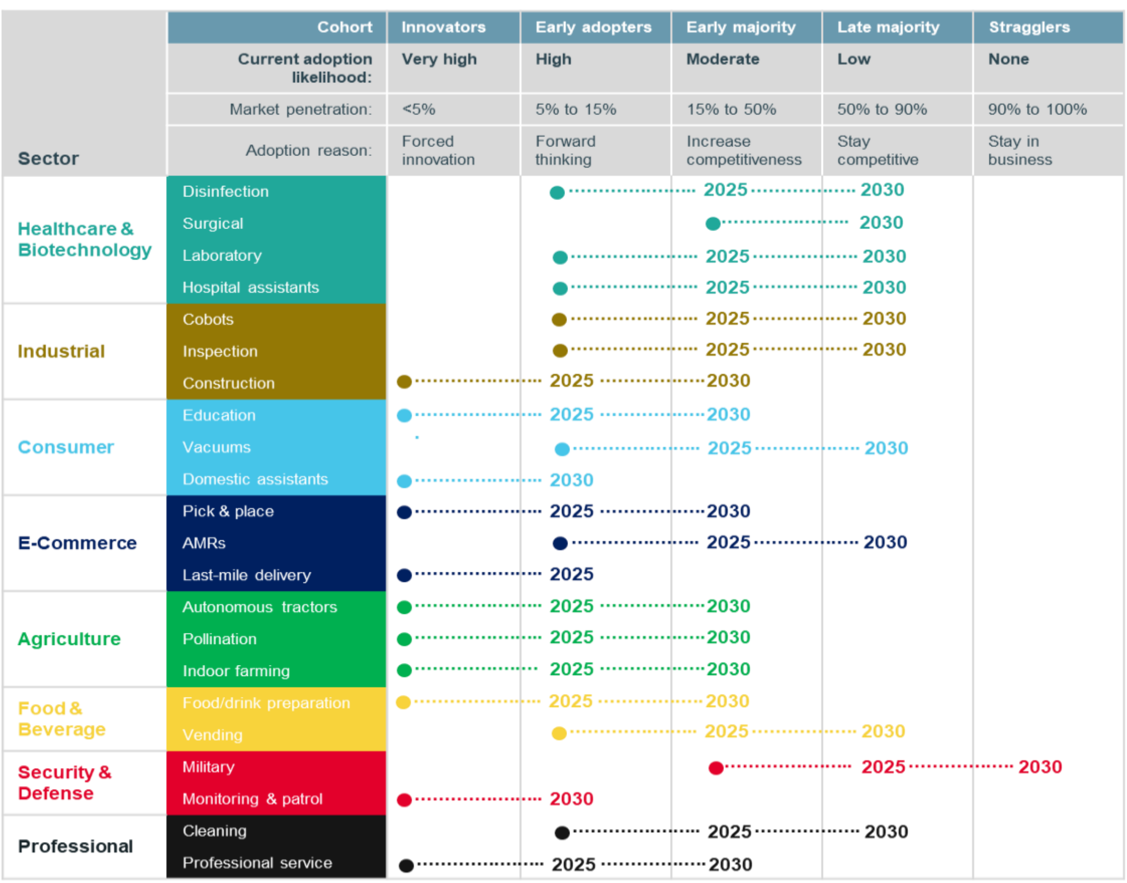


Many countries leading the adoption of robotics technology have established national strategies to support robotics innovation and adoption within targeted industries of national importance. In addition to national strategies, China, South Korea, Japan, and Taiwan all have robust public programs that subsidize the adoption of robotics technology for small and medium-sized enterprises as well as favorable tax policies that encourage the use of advanced technologies. Comparatively, the United States supports fundamental robotics R&D through the National Robotics Initiative but does not have a national strategy to help translate R&D to market and encourage the adoption of robotics technology within other sectors.[21] In light of an uncoordinated national robotics strategy, states such as Massachusetts can look internationally for inspiration on how to lead robotics innovation initiatives. Examples of national robotics strategies can be found in Appendix A.

Robot Utilization across Sectors

Society is on the precipice of a new technological era in which advances in robotic hardware, software and complementary technologies have enabled the integration of robotics in environments beyond early adopters in industrial settings. Industrial robots used in manufacturing environments (i.e. automotive, electronics, food processing, plastics & chemicals, and metal & machinery) remain the most common applications but service robots are increasingly present in our workplaces, homes, healthcare centers, and public spaces. Service robots are robots that augment human performance in settings outside manufacturing. The fastest growing sectors for service robot adoption include transportation & logistics, defense, medical & rehabilitation, hospitality, and agriculture.[22]

Figure 13 | Global Robotics Adoption Forecast Across Sectors



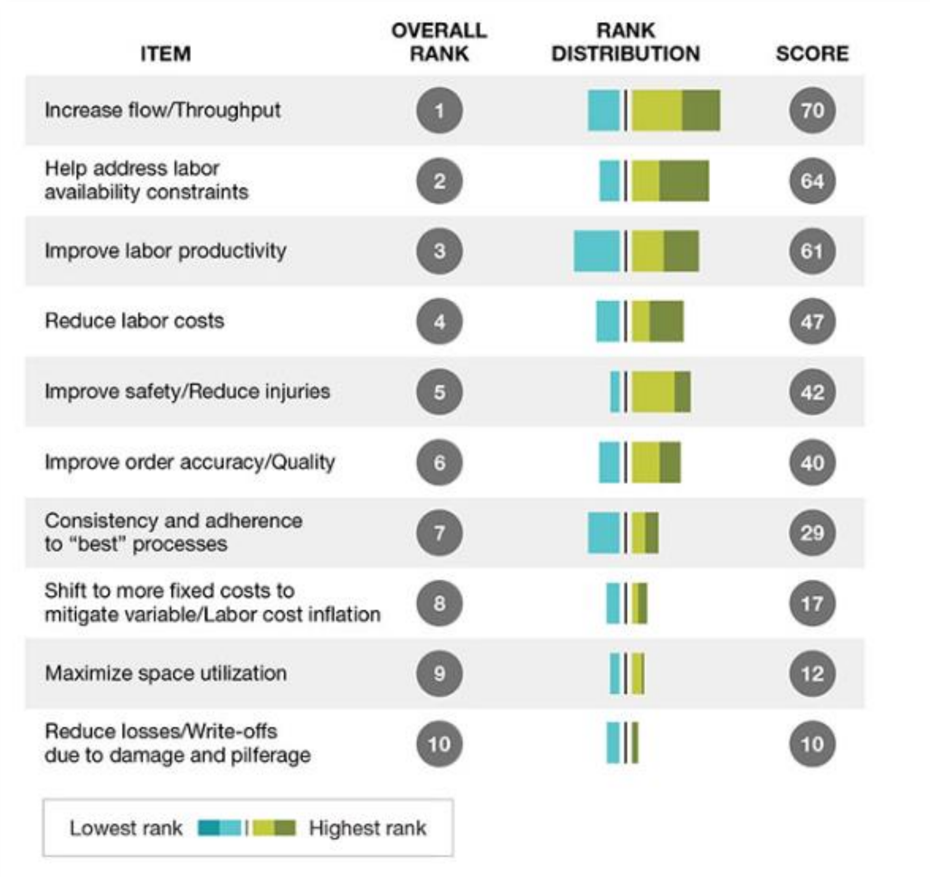
According to data from Pitchbook presented in Figure 13, robotics adoption is expected to become widespread or moderately widespread in multiple sectors by 2030. Robotic applications within three strong sectors of Massachusetts' innovation economy (healthcare, industrial, and defense) are anticipated to make significant gains in user adoption, with more than half of the market utilizing robots in some form by 2030. Robots will play greater roles in other sectors as well, such as agriculture and consumer applications in everyday life, but are unlikely to become ubiquitous over the medium term

Factors Driving Robotics Adoption

As robotics technology becomes more common across sectors, it is important to understand why companies are adopting robotics and automation in their daily operations. The 2022 Intralogistics Robotics Survey conducted by Peerless Research Group highlights both the drivers and barriers to adoption of robotics systems.[23] Although the survey targeted the supply chain and logistics industry, it is a good proxy for the overall sentiment towards adoption.

52% of the survey respondents indicated they are currently using robots in their warehouses or plan to adopt robotic systems within the next three years. A ranking of the top factors motivating organizations to integrate robotics into warehouses and distribution centers is seen in Figure 14. Notably, companies are not looking to replace labor with robots. Instead, they are looking to gain value and process improvements by augmenting the capabilities of human workers and enable increased throughput.

Figure 14 | Top Factors Driving Adoption of Robotics in Warehouses & Distribution Centers



ITEM	OVERALL RANK	RANK DISTRIBUTION	SCORE
Increase flow/Throughput	1		70
Help address labor availability constraints	2		64
Improve labor productivity	3		61
Reduce labor costs	4		47
Improve safety/Reduce injuries	5		42
Improve order accuracy/Quality	6		40
Consistency and adherence to "best" processes	7		29
Shift to more fixed costs to mitigate variable/Labor cost inflation	8		17
Maximize space utilization	9		12
Reduce losses/Write-offs due to damage and pilferage	10		10

Lowest rank – Highest rank

Increasing throughput and addressing labor shortages are the top factors driving the adoption of robotics.

Barriers to Robotics Adoption

48% of survey respondents indicated they have no plans to use robots within the next three years and cited the challenges listed in Figure 15 as the primary barriers to adoption.

Figure 15 | Top Barriers to Adoption of Robotics in Warehouses & Distribution Centers

ITEM	OVERALL RANK	RANK DISTRIBUTION	SCORE
Identifying and achieving return on investment (ROI)	1		51
Lack of internal robotics experience and expertise	2		37
Culture issues and concerns	3		25
Long lead time from initial concept to final project delivery	4		23
Potential disruption of operations/downtime	5		22
Securing project funding	6		21
Unable to identify a realistic use case with reasonable justification	7		20

Lowest rank — Highest rank

Identifying ROI and the lack of internal robotics expertise are the top barriers to adopting robotics.

These responses suggest that realistic business use cases are visible within the industry, but how to integrate systems may not be well understood. Early adopters are demonstrating value and report investments in robotics technology meet or exceed their ROI objectives. However, significant barriers exist for companies that struggle to understand the economics of robotics integration and lack internal expertise on how to select, install, operate, and maintain robotic systems.

There are also significant cultural connotations in the United States around robots that pose barriers to adoption across all sectors and within the public domain. The full benefits of robots cannot be realized because public perception tends to focus on robots' potential for disruption rather than their potential benefits. Ecosystem stakeholders interviewed for this report highlighted a need for the public to learn more about what robots are and how robotic technologies can improve quality of life. This socialization process, however, takes time and requires novel approaches and commitment from public sector leaders to partner with industry to pilot robots within communities. Public deployments and demonstrations of robots can help improve the technology through learning in complex environments while also providing more opportunities to enhance public perception and acceptance.

Recommendations to Encourage the Adoption of Robotics Technology in Massachusetts

1. Develop a strategy to **encourage the integration of robotics across innovation sectors** including healthcare, advanced manufacturing, and defense.
   There is an opportunity for Massachusetts to drive impactful economic growth within its priority sectors by encouraging greater utilization of robotics. Large manufacturers have been able to integrate robotics and automation to augment their workforce, but smaller firms face high capital and training costs. It is recommended Massachusetts ease barriers to adoption of robotics among small and medium sized firms through access to workforce training and capital improvement opportunities. The establishment of integration and implementation centers can help SMEs and end-users learn what types of robotic systems are available, which are the right solution for their needs, and access workforce training through reskilling programs. Targeted investments in integrating robotic technology into key innovation sectors of regional interest present significant opportunities for productivity gains and economic growth.

2. Become the first place DoD looks to source robotics & AI technology by **supporting commercialization of dual-use technologies**
   Recent efforts by the Department of Defense to source from domestic suppliers, combined with the expected increase in demand for military robots and drones over the next decade, present a significant opportunity for Massachusetts to position its robotics ecosystem as a premier source of robotic solutions for DoD. While Massachusetts is already home to a sizable cluster of defense robotics companies, stakeholders should consider the strategic development and commercialization of technologies that hold broad appeal to defense and commercial customers to capitalize on favorable trends in DoD procurement.

WORKFORCE & TALENT

Executives across industries express growing needs to upskill a significant share of their workforce due to advancements in automation and digitization. As we see new robotics and automation systems introduced in our daily lives for personal and professional use, it is essential that we train a workforce that can efficiently use these new technologies and ensure equitable access to jobs in robotics fields. Massachusetts is widely recognized for its high-quality elementary, secondary, and postsecondary education systems. There is also a network of workforce development agencies in the Commonwealth providing training opportunities to prepare individuals for the future of work that can be leveraged to develop additional training programs that address shortages in robotics occupations.

Growth in Robotics-Related Occupations

This report analyzed employment trends in robotics-related middle-skill and high-skill occupations. Middle-skill occupations, primarily at the technician level, are central to installing, operating and maintaining robotic systems. High-skill occupations, such as engineers, design and build robotic systems.

Robotics Technicians

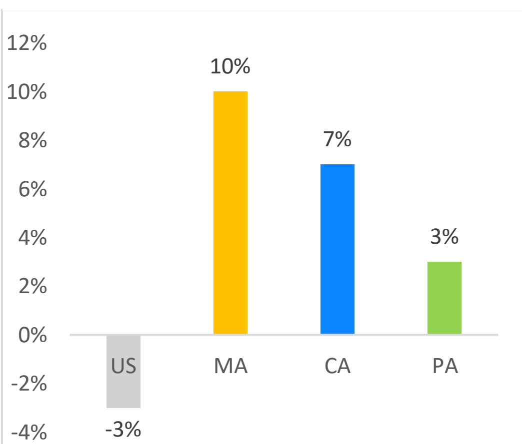
Robotics Technicians install, test, or maintain robotic equipment or related automated production systems.

Middle-skill technical robotics talent is critical to meeting the growing demands of industry 4.0. A 2021 MassTech study on the robotics needs of New England manufacturing firms found that the roles with the strongest anticipated growth are mechatronics technicians, electrical and mechanical engineering technicians, and robotics installation and deployment technicians (which collectively will be referred to as "robotics technicians"). Survey respondents expressed concern about the ability to fill open positions and the need for extensive on-the-job training, particularly for mechatronics technicians, which today require a higher level of technical skills and training than in the past. A quote from one of the survey respondents summarizes the shifting skill requirements "What engineers were doing three years ago, technicians are now expected to do."[24]

Skill Requirements for Robotics Technicians

- Maintenance & Trouble shooting
- Electrical Systems
- PLC (Programmable Logic Controllers)
- Electronics & Controls
- Robot Programming
- Mechanical Systems
- Fluid Power
- Safety & Risk Assessment

Figure 16 | Projected Growth in Robotics Technician Roles (2020-2030)



Data from the Bureau of Labor Statistics (BLS) shown in Figure 16, indicates the number of robotics technician jobs in Massachusetts is expected to increase 10% by 2030. This represents an average of 100 new robotics technician jobs each year. These technicians play an important role in the Massachusetts innovation economy and are essential to robotics and advanced manufacturing sectors. Massachusetts must develop a pipeline to attract and retain robotics technicians in order to remain competitive, particularly as more industries adopt robotics technology and robotics roles become more ubiquitous across sectors.

Robotics Engineers

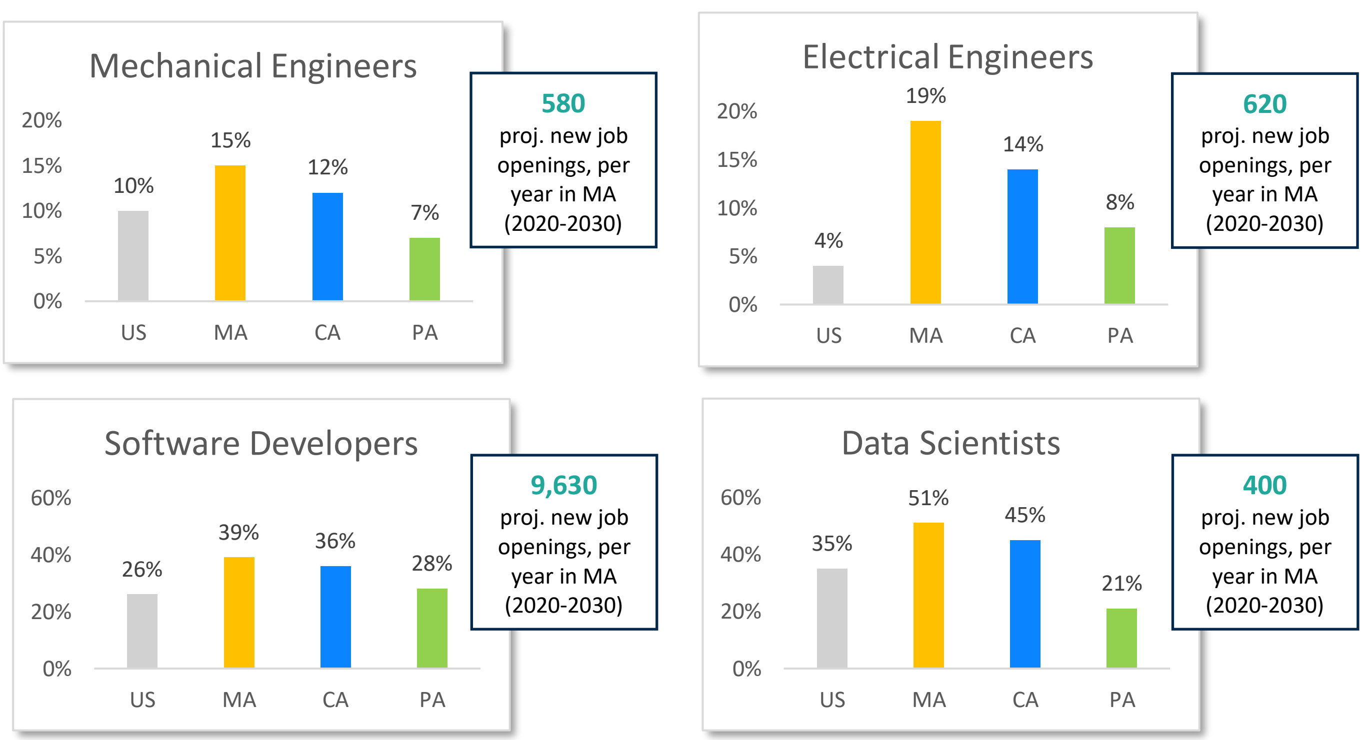
Robotics Engineers research, design, and develop robotic systems. Roles as robotics engineers combine skills in electrical engineering, mechanical engineering, and computer systems engineering. Since robotics engineers have a variety of job titles and operate in a wide array of industries, this report highlights five engineering roles (listed in Table 7) critical to the growth of the robotics industry.

Table 7 | Types of Robotics Engineers[25]

Mechanical Engineer	Specializes in designing the mechanical components of robotics systems, including the physical structures, joints, actuators, and end-effectors
Electrical Engineer	Focuses on the electrical systems of robots, designing circuits, sensors, and actuators to enable communication and control within the robotic framework
Software Engineer (Robotics Programmer)	Specializes in writing and implementing the software code that controls the behavior, motion, and functionality of robotics systems
Computer Vision Engineer	Specializes in creating algorithms and systems that enable robots to interpret visual information from cameras, lidar, and other sensors for perception and decision-making
Machine Learning Engineer	Applies machine learning techniques to enhance the capabilities of robots, enabling them to adapt, learn from experience, and improve their performance over time

Data from BLS presented in Figure 17 shows Massachusetts is leading its peer states in terms of expected employment growth within each of the engineering roles analyzed. BLS does not track occupational data for Computer Vision Engineers or Machine Learning Engineers. The "Data Scientist" occupation is used as proxy to highlight employment trends related to AI, ML, and computer vision.

Figure 17 | Projected Growth in Robotics Engineer Roles (2020-2030)

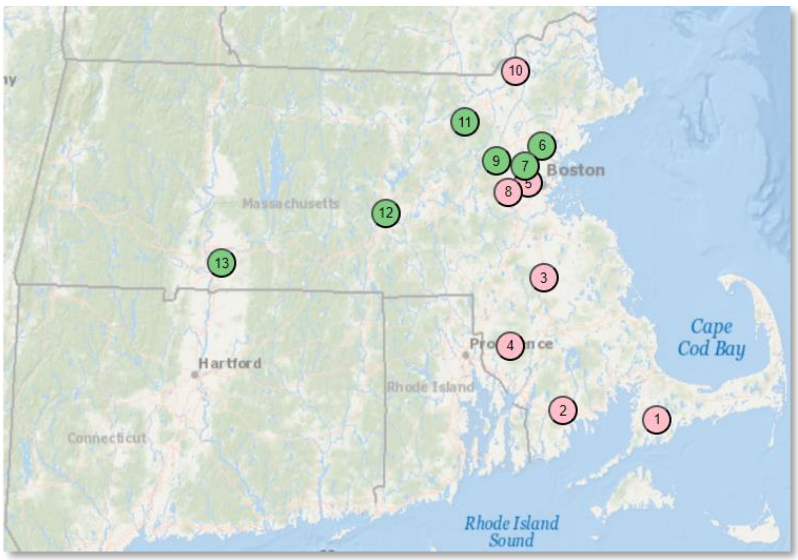


K-12 Robotics Education

Given the projected job growth across a range of robotics roles in Massachusetts, it is essential the Commonwealth build a strong pipeline of technical talent to meet the needs of the growing robotics industry.

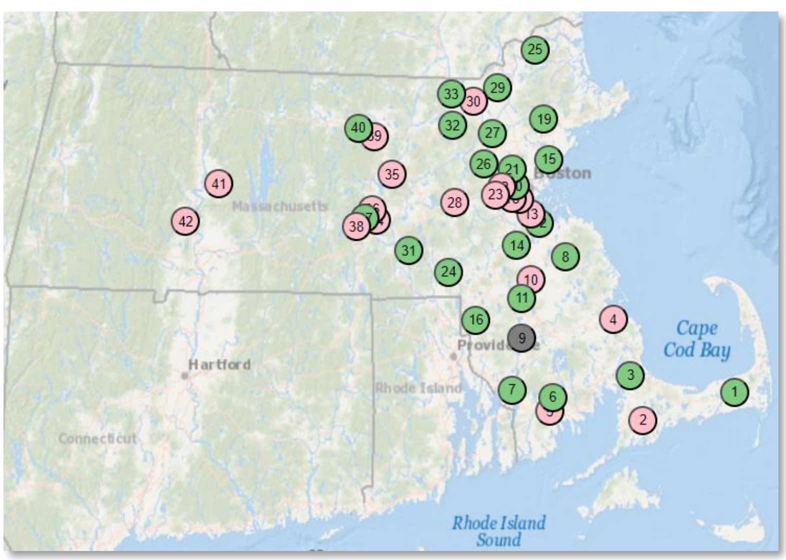
There are several paths of secondary technical education in Massachusetts that prepare students for jobs in high-demand fields within robotics and engineering. The most comprehensive path flows through Career and Vocational Technical Education (CVTE) Programs established under MA General Laws (Chapter 74) and the federal Perkins Act (non-Chapter 74). There are six Chapter 74 and seven non-Chapter 74 Robotics & Automation programs in Massachusetts, represented in Figure 18 by the green and pink circles, respectively. General engineering programs are more common with 23 Chapter 74 programs and 18 non-Chapter 74 programs as represented in Figure 19 by the green and pink circles, respectively.

Figure 18 | Robotics & Automation CVTE Programs in MA



11
Robotics & Automation CVTE programs

Figure 19 | Engineering Technology CVTE Programs in MA



41
Engineering CVTE programs

Post-Secondary Robotics Education

15
Universities specializing in robotics and engineering

Massachusetts is home to 15 colleges and universities offering at least 3 or more degrees in robotics-related disciplines such as computer engineering, electrical engineering, mechanical engineering, and industrial engineering. Of these 15 schools, 4 offer degrees specifically focused on robotics and automation in addition to a variety of engineering degrees. These schools (Boston University, Northeastern, Tufts, and WPI) are indicated with an asterisk (*) in Table 8. WPI was the first school in the nation to offer robotics degrees at all three bachelor's, master's, and doctoral levels. Similarly, Tufts University is home to the nation's first master's and doctorate degrees in human-robot interaction, which build upon its undergraduate human factors engineering degree.

Table 8 | MA Colleges and Universities with Specialties in Robotics and Engineering Disciplines

- Boston University* - Boston
- Harvard University - Cambridge
- Mass Maritime Academy - Bourne
- Merrimack College – North Andover
- MIT - Cambridge
- Northeastern University* – Boston
- Olin College of Engineering – Needham
- Stonehill College – Easton
- Tufts University* - Somerville
- University of Massachusetts - Amherst
- University of Massachusetts - Dartmouth
- University of Massachusetts - Lowell
- Wentworth Institute of Technology - Boston
- Western New England University - Springfield
- WPI* - Worcester

Four-year colleges are not the only pathway to a career in robotics. There are 12 two-year institutions in Massachusetts offering at least 3 or more associate degrees or certificate training programs in robotics-related fields. Of these 12 schools, 6 offer programs specifically focused on robotics and automation. These schools (Ben Franklin Institute of Technology, Bristol Community College, Cape Cod Community College, Mount Wachusett Community College, Quinsigamond Community College, and Springfield Technical Community College) are indicated with an asterisk (*) in Table 9.

6
2-year degree programs or 1-year certificate programs focused on robotics and automation

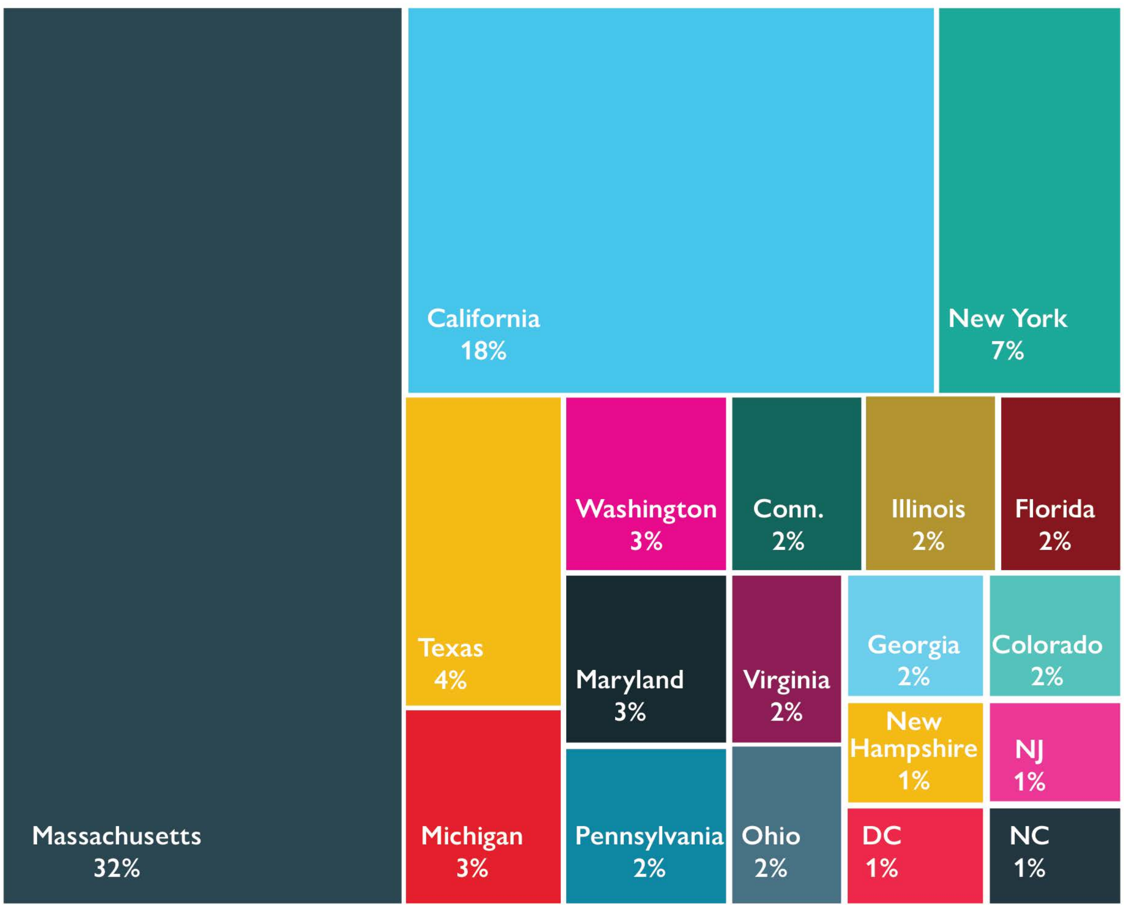
Table 9 | MA 2-year Academic Institutions with Robotics-related Training Programs

- Ben Franklin Institute of Technology*, Boston
- Bristol Community College, Fall River
- Bunker Hill Community College, Boston
- Cape Cod Community College*, Barnstable
- MassBay Community College, Wellesley
- Massasoit Community College, Brockton
- Middlesex Community College, Bedford
- Mt Wachusett Community College*, Gardner
- North Shore Community College, Danvers
- Northern Essex Community College, Haverhill
- Quinsigamond Community College*, Worcester
- Springfield Tech. Community College*, Springfield

Retaining Graduates in Robotics-Related Fields

When it comes to retaining robotics-related talent, Massachusetts is somewhat successful. According to data obtained from Emsi Burning Glass, Massachusetts retains 32% of doctoral degree holders from top Massachusetts schools. Additionally, the state retains 40% of robotics-related bachelor's and master's degree holders. By comparison, 61% of robotics-related doctoral graduates and 70% of robotics-related bachelor's and master's degree holders from top California schools remained in California (for Pennsylvania, these figures are 24% and 40%, respectively). There is an opportunity for the Massachusetts robotics ecosystem organizations and industry partners to engage earlier with students to create a sense of community and provide job opportunities that will keep highly skilled engineers and roboticists in the Commonwealth.

Figure 20 | Robotics-Related Doctorate Degree Holders from Select MA Universities, by State of Residence



Note: robotics-related fields include mechanical engineering, electrical engineering, and computer science; data collected on graduates from MIT, Harvard University, WPI, Boston University, Northeastern University, and Brandeis University.

Recommendations to Grow the Robotics Workforce in Massachusetts

1. Engage industry partners to **scale project-based robotics education** in Massachusetts high schools.

Educational and workforce development programs that engage diverse populations in experiential learning and training will be critical in meeting the employment needs of robotics and robotics-enabled industries. There is an opportunity to facilitate connections between educators and industry to design and implement experiential learning opportunities that build on foundational theories while exposing students to the robotics community through project-based learning, mentorship and internships. Industry-designed and guided projects can be implemented across vocational and traditional schools alike.

PROGRESS UPDATE → MassTech has awarded a grant to MassRobotics to scale its Jumpstart Fellowship program to expand opportunities for diverse Massachusetts high school girls to learn about STEM careers in robotics and develop their professional networks through direct engagement with industry professionals. The Jumpstart program was started in 2021 and has run 4 cohorts as of 2024. 2024 is the first year the program will be offered in both Boston and Lowell. The program runs from January – May and participants meet weekly on Saturdays and during February vacation. Upon graduation from the program, participants receive a $1,000 stipend and are offered paid summer internships with local robotics companies.

2. Establish **training programs for robotics technicians**

The shortage of technicians trained to operate robots and automated systems hinders robotics adoption across the Commonwealth. To realize the full potential of robotics technology, the Commonwealth of Massachusetts must leverage existing and create new programs to grow the pool of trained technicians capable of working alongside robots.

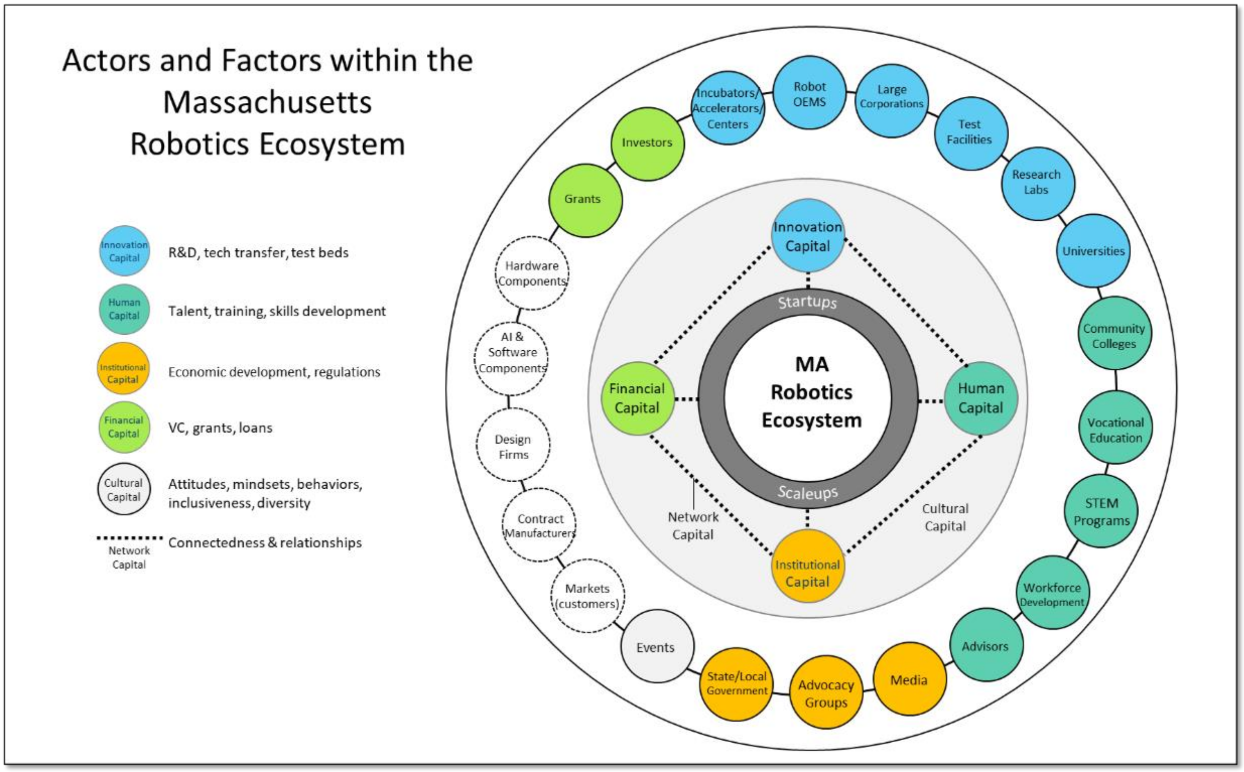
Training programs for middle-skill technicians should be industry-guided to ensure industry 4.0 processes are incorporated into the curriculum. Greater industry involvement provides real-world experience and connections for students and can be effective in addressing critical shortages in robotics technicians by better identifying hiring opportunities and directing students to their preferred career paths.

PROGRESS UPDATE → As of 2023 MassTech has partnered with the Northeast Advanced Manufacturing Consortium (NAMC) to develop a registered robotics technician apprenticeship program. The program has been approved by the Division of Apprenticeship Standards and will train workers to install, operate, and maintain robotics systems. MassTech, NAMC, and related technical instruction partners are finalizing curriculum and lining up employers to participate in the first year of the apprenticeship which is expected to begin in Fall 2024.

ECOSYSTEM DEVELOPMENT

All the right components to grow a thriving robotics ecosystem are present in Massachusetts. Based on Feld & Hathway's theory of ecosystem building depicted in Figure 21, Massachusetts has six capital factors required for a sustainable ecosystem: 1) innovation capital, 2) human capital, 3) institutional capital, 4) financial capital, 5) network capital, and 6) cultural capital.[26] The outer ring of the illustration represents a rich pool of ecosystem actors in the form of universities, test facilities, community colleges, workforce boards, state & local government, advocacy groups, customers/end-users, contract manufacturers, design firms, component suppliers, investors, and more. Robotics companies in the startup and scaleup stages are at the heart of the ecosystem. The success of young, innovative companies surrounded by a community of support is key to the continued growth of the Massachusetts robotics sector.

Figure 21 | Actors & Factors within the Massachusetts Robotics Ecosystem



The previous sections of this report have laid out the state of innovation capital, human capital, and financial capital within the robotics cluster. It is how these factors interact (network capital and cultural capital) and how they are supported (institutional capital) that turns a cluster of related assets into an interconnected ecosystem. The network capital is extremely strong in Massachusetts. The large presence of established and incumbent robotics companies provides a robust pool of industry mentors with decades of experience who are willing to guide the next generation of robotics founders. There is strong anecdotal evidence that the sense of community and connectedness felt within the Massachusetts robotics ecosystem is unrivaled.

The cultural capital within the ecosystem has been on full display in recent years with the emergence of large scale ecosystem events and smaller community gatherings. A few noteworthy events include:

- **RoboBoston** - MassRobotics has held RoboBoston since 2018 and each year it has attracted over 4,500 people. The event is free and open to the public and includes demonstrations featuring 100 robots, presentations from robotics companies and universities, and hands-on interactions with robots that greatly enhance understanding of robot capabilities and beneficial use-cases among the general public. This two-day event also features school field trips and a career fair that attracts more than 1,250 job seekers.

- **Robotics Expo & Summit** – the world's leading commercial robotics development event is hosted over two days each spring in Boston. The 2023 event featured 2,500+ attendees and 60+ speakers.

- **Women in Robotics Gala** – In 2023 MassRobotics hosted the inaugural Women in Robotics Gala to honor women making invaluable contributions to the field of robotics. The event included the Robotics Medal award ceremony – the world's first major prize to recognize the wide-ranging impact of female researchers on the development of robotics.

The progress made in coordinating ecosystem activity has largely centered around Greater Boston. There is an opportunity to align strategic partners from regions across Massachusetts to create an integrated ecosystem of robotics support throughout the Commonwealth. However, the comprehensive institutional capacity necessary to integrate stakeholders, create new initiatives, and promote the ecosystem has not existed until recently.

Robotics has been recognized as a key priority industry for the Commonwealth of Massachusetts. In 2023, the Massachusetts Legislature approved $5 Million in ARPA funding to be allocated to develop the institutional capacity necessary to grow the robotics cluster. This includes the creation of a new division within the Innovation Institute at MassTech to catalyze a comprehensive statewide cluster development effort for robotics that will focus on expansion of R&D, testing, commercialization, and workforce development. The establishment of the department builds on MassTech's $28 million in investments in the state's robotics sector over the past decade.

While the state's $5 million investment marks a major milestone, it is an interim solution funded for a two-year period. The Massachusetts economic development plan released by the Healey-Driscoll Administration in December 2023 called for a more permanent Center for Robotics to be housed at MassTech with an emphasis on further developing ecosystem connections, particularly between stakeholders in the AI and robotics clusters.

In the meantime, Massachusetts must continue working to tell its story of robotics success. Pennsylvania has recently received significant federal funding to advance its robotics ecosystem and has started a marketing campaign to position itself as the "robotics capital of the world." Almost every data point in this report runs counter to that claim with Massachusetts' advancements in innovation and commercialization outpacing Pennsylvania, but perception is important. A major opportunity exists for representatives from the Massachusetts robotics community to become more visible in promoting the ecosystem at major robotics events around the world and through social media.

Dedicated support from the MassTech Robotics Department will propel the evolution and growth of the Massachusetts robotics ecosystem by providing the infrastructure necessary to integrate diverse stakeholders, create new initiatives, promote the ecosystem as a whole, capture learnings and data to track progress, and develop strategic sustainability plans to ensure Massachusetts' global leadership in robotics.

Recommendations to Strengthen the Massachusetts Robotics Ecosystem

1. Establish a **state-wide industry “concierge”** to facilitate connections within the ecosystem.

Enhanced institutional capacity can help track and increase visibility into activities occurring within the cluster and enable the facilitation of connections between complementary actors. The creation of an industry “concierge” or liaison would be beneficial to facilitate connections across the entire regional robotics value chain. In particular, this service can help advance the localization of supply chains and the production of robotic components and systems through improved connections between startups, local manufacturers, and component suppliers. The “concierge” can also provide business development services including helping startups access test sites and attracting robotics companies based outside Massachusetts looking to expand in the Commonwealth. In general, the “concierge” can serve as the front door to the robotics ecosystem in Massachusetts and facilitate knowledge sharing and relationship building.

PROGRESS UPDATE → The robotics department within the Innovation Institute at MassTech is led by a director who will fill this role.

2. Launch a **unified marketing campaign** to highlight the strengths and opportunities within Massachusetts’ robotics industry

Given the strength and potential growth of robotics in Massachusetts, the ecosystem can benefit from greater visibility inside and outside the Commonwealth. To this end, a unified marketing campaign can show audiences within Massachusetts and those across the world that Massachusetts is a global hub for robotics innovation, commercialization, adoption, and talent. This campaign should include a robust digital presence through a dedicated website and active social media management, alongside a strategic presence at leading industry tradeshows. Such an approach will showcase the ecosystem's diversity and strengths, attract global investment, and recruit top talent, effectively establishing Massachusetts as the premier destination for robotics innovation and collaboration.

3. Establish a **robotics innovation network** to connect the robotics community in Massachusetts and enable collaboration across institutions and disciplines.

A robotics innovation network across Massachusetts would consist of specialized centers, or "nodes," across the state, each aligned with regional industrial strengths to support sectors like advanced manufacturing, healthcare, agriculture, and defense. These nodes would provide critical testing facilities, STEM education programs, and integration support services to assist local businesses in adopting new robotics technologies and reskilling their workforce. Additionally, a shared resource pool of business development and technology transfer experts would be accessible across the network, enhancing the state's competitive advantage by fostering innovation, facilitating commercial adoption, and attracting top-tier talent to the robotics sector in Massachusetts.

Conclusion

As we navigate through an era marked by rapid technological evolution and shifting economic landscapes, regions with strong robotics clusters will hold a distinct competitive advantage in the global economy of the future. Massachusetts' robust innovation economy, driven by leading university R&D labs, a highly skilled workforce, and culture of entrepreneurship, is primed to capitalize on booming robotics market, both as a force for economic development and societal good. However, as global competition increases with many nations and regions actively vying to become the next "global hub for robotics," this potential can only be realized through a concerted effort to bolster innovation, facilitate commercialization, encourage adoption, and cultivate talent within the robotics sector. The imperative is clear: to transform the potential of the state's robust robotics ecosystem into tangible economic success and societal benefits.

The recommendations outlined in this report present a roadmap for Massachusetts to strengthen its leadership in robotics. These recommendations focus on five areas: 1) innovation and research collaboration to bridge the gap between theoretical research and practical application, 2) commercialization and entrepreneurial support to increase the rate at which innovative ideas are transformed into marketable products, 3) adoption and integration across various sectors to unlock productivity gains and operations efficiencies, 4) workforce development to prepare students for the jobs of the future, and 5) ecosystem development to facilitate effective collaborations and ensure that the Commonwealth's robotics sector operates as a cohesive, dynamic entity.

These recommendations are foundational steps towards building a future where technology serves the common good. By integrating the recommendations provided, Massachusetts can streamline its innovation pipeline, enhance commercialization efforts, boost adoption across key sectors, and develop a skilled workforce adept at navigating the future of robotics. Central to these efforts is the necessity of fostering deep collaboration among academia, industry, and government, alongside targeted investments that drive growth and innovation in robotics.

As Massachusetts stands on the cusp of a new era of robotization, the strategic growth of its robotics ecosystem represents a critical opportunity. By adopting a holistic approach that encompasses innovation, commercialization, adoption, talent development, and ecosystem coordination, the Commonwealth can transform its robotics potential into a catalyst for economic prosperity and societal well-being. The implementation of these recommendations will not only secure Massachusetts' leadership in the global robotics arena but also demonstrate how technology, when harnessed thoughtfully, can improve the lives of people across the state and beyond. In doing so, Massachusetts will not just navigate the future of robotics; it will shape it, ensuring a future where technology serves to uplift and empower.

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Appendix A

Examples of National Robotics Strategies

Snapshot of National Robotics Strategies	
China	**Made in China 2025 -** In 2019 the Chinese government invested 577 million USD in the development of intelligent robotics and its 5 year industry development plan aims to advance the development and use of robotics in the country's top 10 core industries.
Japan	**New Robot Strategy -** Japan's budget for robotics R&D increased to 930.5 million USD in 2022 with intentions to make the country the leading robotics innovation hub in the world with action plans for robotics in manufacturing, healthcare, agriculture, and infrastructure
South Korea	**The Intelligent Robot Development & Supply Promotion Act –** South Korea released its 4th national plan for intelligent robots in 2023 which identified core robotics technologies: servomotors, reducers, sensors, grippers, controllers, autonomous movement software, autonomous operation software and human-robot interaction. This plan involves an investment of 3 trillion won (2.3 billion USD) by 2030 to nearly quadruple the domestic robotic market.
Denmark	**Odense & Seoul MOU** – In 2024, the City of Odense, Denmark and the City of Seoul, South Korea signed an agreement to build a collaborative robotics ecosystem and facilitate knowledge sharing between their respective robotics clusters.
European Union	**Horizon 2020 -** The EU's 8th Framework Program dedicates an estimated 780 million USD over 7 years to support the development of robotics applications for manufacturing, commercial and healthcare uses. Additionally, the EU's Work Program includes $173 million for investments in promising new applications and core technologies such as AI and cognition and socially cooperative human-robot interactions.
Germany	**PAiCE Program -** As Europe's largest robot market, Germany has included the development of robotics in its High-Tech Strategy through the allocation of 345 million USD over five years towards the establishment of digital industry platforms and the collaboration of companies using the platforms.
India	**National Strategy for Robotics (NSR) -** The Ministry of Electronics and Information Technology has outlined a draft for a strategy that aims to strengthen the innovation cycle of robotic technology and position India as a leader in robotics by 2030. This strategy, released in September 2023, is focused on sectors like manufacturing, agriculture, healthcare, and national security, aligning with the Make in India 2.0 Framework.
United States	**National Robotics Initiative (NRI) -** NRI supports fundamental robotics R&D through a budget of 35 million USD in 2019 and 14 million USD in 2021. Additional funding for robotics applications in defense and space is provided by the DoD.

Appendix B
Methodology & Data Sources

The figures in this report are created using data from various public and private sources. This section provides further detail on these sources and the calculations used to generate the figures in the report.

Table 1 | Representative Massachusetts Robotics Research Labs
Compiled from stakeholder interviews and web searches

Figure 1 | Federal R&D Obligations per Employed Worker
Data on federal R&D obligations per employed worker in Massachusetts, California, and Pennsylvania are sourced from the Science and Engineering State Indicators program of the National Center for Science and Engineering Statistics. The specific indicator referenced is State Indicator S-42: Federal R&D Obligations per Employed Worker

Figure 2 | Federal R&D Obligations by Funding Agency
Data on federal R&D obligations by funding agency in Massachusetts, California, and Pennsylvania are sourced from Data Table 61 of the FY 2021 Survey of Federal Funds for Research and Development, a survey conducted by the National Science Foundation.

Figure 3 | SBIR & STTR Awards to Massachusetts Robotics Sector (2012–2022)
Data on Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Awards are sourced from the Small Business Administration's SBIR webpage. Robotics-related awards are identified through a keyword search for "robot" or "robotic", which filtered for awards containing either of these words in the award title or abstract. The data were then manually checked to confirm that the awards are directed toward robotics-related projects.

Figure 4 | MA Share of Robotics-Related Patents
Data on robotics-related patents are sourced from the U.S. Patent and Trade Office's Patents View tool. Robotics-related patents in Massachusetts are defined as patents in which 1) the terms "robot" or "robotic" appear in the patent title or abstract and 2) the inventor who filed the patent resides in Massachusetts.

Table 2 | States Producing the Most Robotics Patents in 2022 and 2023
Data on robotics-related patents are sourced from the U.S. Patent and Trade Office's Patents View tool. Robotics-related patents for each state are defined as patents in which 1) the terms "robot" or "robotic" appear in the patent title or abstract and 2) the inventor who filed the patent resides in that state.

Figure 5 | Massachusetts Robotics Firms by Technology Segment
Firm-specific data is sourced from Pitchbook, which uses a classification system called "verticals" to categorize firms by industry. Massachusetts robotics firms are defined as 1) those in the "Robotics and Drones" and "Autonomous Cars" verticals and 2) those who are headquartered in Massachusetts. Each of these firms was then manually tagged with a primary segment based on a scan of the firm's website and other publicly available information about the firm's activities. Resident firms of MassRobotics were also included in this list.

Figure 6 | Robotics Startup Formation Rates – CA, MA, PA (2012-2023)

Startup formation data is sourced from Pitchbook using the "robotics and drones" and "autonomous cars" industry verticals. Resident firms of MassRobotics with Massachusetts-based headquarters were included in the startup formation numbers for Massachusetts.

Table 3 | Robotics Test Sites in Massachusetts
Compiled by MassRobotics' 2020 Test Facility Study and stakeholder interviews

Table 4 | VC raised by robotics companies in 2022 and 2023 – peer state comparison

Figure 7 | MA Robotics VC Investment, (2010-2023)
Venture Capital data is sourced from Pitchbook filtered by "robotics and drones" and "autonomous cars" industry verticals and deal types including "seed", "early-stage", and "later-stage".

Figure 8 | CA Robotics VC Investment, (2010-2023)
Venture Capital data is sourced from Pitchbook filtered by "robotics and drones" and "autonomous cars" industry verticals and deal types including "seed", "early-stage", and "later-stage". The California figures presented exclude companies tagged with the "autonomous cars" industry vertical in Pitchbook, but primarily operating in the automotive industry as electric vehicle producers or rideshare companies (i.e. Rivian, Lucid, Lyft).

Figure 9 | PA Robotics VC Investment, (2010-2023)
Venture Capital data is sourced from Pitchbook filtered by "robotics and drones" and "autonomous cars" industry verticals and deal types including "seed", "early-stage", and "later-stage". The Pennsylvania figures display venture capital investment with and without an outlier $1B early-stage investment to Uber Advanced Technology Group in 2019 which skews the overall PA robotics VC numbers higher.

Figure 10 | Leading Industry Verticals Attracting Robotics VC Investment Since 2020
Venture Capital data is sourced from Pitchbook filtered by "robotics and drones" and "autonomous cars" industry verticals. Capital invested by verticals is assessed as a percentage of total capital invested in each state for the cumulative years of 2020, 2021, 2022, and 2023.

Table 5 | Publicly Traded US Robotics Companies
Publicly traded company data is sourced from Pitchbook filtered by the "robotics and drones" industry vertical for all US headquartered companies that completed publicly listings as of December 31, 2023. Exit types include IPO, SPACs (reverse mergers), and secondary offerings that listed the company on a major US exchange (NYS or NAS) for the first time. Market cap figures were as of February 24, 2024. Data categories and visualization inspired by FPrime Capital's State of Robotics report.

Table 6 | M&A Deals >$50M – MA Robotics Companies, (2012-2023)
M&A deal data is sourced from Pitchbook filtered by the "robotics and drones" industry vertical for all US headquartered companies that completed mergers & acquisitions as of December 31, 2023. Acquisition value is the disclosed deal size. Data categories and visualization inspired by FPrime Capital's State of Robotics report.

Figure 11 | Robot Density in the Manufacturing Industry, 2022

Figure 12 | Annual Installations of Industrial Robots – 15 Largest Markets, 2022
Robot density data is sourced from the IFR World Robotics 2023 report. Robot density measures the number of industrial robots per 10,000 workers in the manufacturing industry.

Figure 13 | Global Robotics Adoption Forecast Across Sectors
Adoption forecast produced by Pitchbook

Figure 14 | Top Factors Driving Adoption of Robotics in Warehouses and Distribution Centers

Figure 15 | Top Barriers to Adoption of Robotics in Warehouses and Distribution Centers
This data is sourced from the 2022 Intralogistics Robotics Survey conducted by Peerless Media. The survey results are from 180 respondents with involvement in robotic automation systems in over a dozen industries spanning manufacturing, wholesale and retail trade, logistics and transportation, and other non-manufacturing industries.

Figure 16 | Projected Growth in Robotics Technician Roles (2020-2030)
Occupation data is sourced from the U.S. Bureau of Labor Statistics Occupational Projections and Worker Characteristics, 2020-2030. Employment data for the "electro-mechanical and mechatronics technologists and technicians" job title is used a proxy for robotics technician roles. Data was retrieved from the BLS O*Net Online data sets.

Table 7 | Types of Robotics Engineering Roles
Sourced from careerexplorer.com

Figure 17 | Projected Growth in Robotics Engineer Roles (2020-2030)
Occupation data is sourced from the U.S. Bureau of Labor Statistics Occupational Projections and Worker Characteristics, 2020-2030. Data was retrieved from the BLS O*Net Online data sets.

Figure 18 | Robotics & Automation CVTE Programs in Massachusetts

Figure 19 | Engineering Technology CVTE Programs in Massachusetts
Maps compiled by the Massachusetts Department of Elementary and Secondary Education's Career/Vocational Technical Education department. https://masswbl.org/pathwaymapping/

Table 8 | MA Colleges and Universities with Specialties in Robotics and Engineering Disciplines

Table 9 | MA 2-year Academic Institutions with Robotics-related Training Programs
Compiled from stakeholder interviews and web searches

Figure 20 | Robotics-related Doctorate Degree Holders from select MA Universities, by State of Residence
Data on the locations of Massachusetts university graduates are collected from Lightcast (formerly Emsi Burning Glass), a labor market analytics platform. This figure defines robotics-related fields as mechanical engineering, electrical engineering, and computer science. The Massachusetts universities whose graduates are the subject of this figure are the Massachusetts Institute of Technology, Harvard University, Worcester Polytechnic Institute, Boston University, Northeastern University, and Brandeis University.

Figure 21| Actors & Factors within the Massachusetts Robotics
Visualization inspired by Feld & Hathaway's 2020 book *The Startup Community Way*.