# FOREFRONT:

## Securing Pittsburgh's Break-out Position in Autonomous Mobile Systems.

**Performed for:** Regional Industrial Development Corporation and the Greater Pittsburgh Chamber of Commerce, with funding support provided by the Richard King Mellon Foundation

**Prepared by:** TEConomy Partners, LLC

September 2021

RIDC
Regional Industrial Development Corporation

Greater Pittsburgh Chamber of Commerce
an affiliate of the Allegheny Conference

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# EXECUTIVE SUMMARY

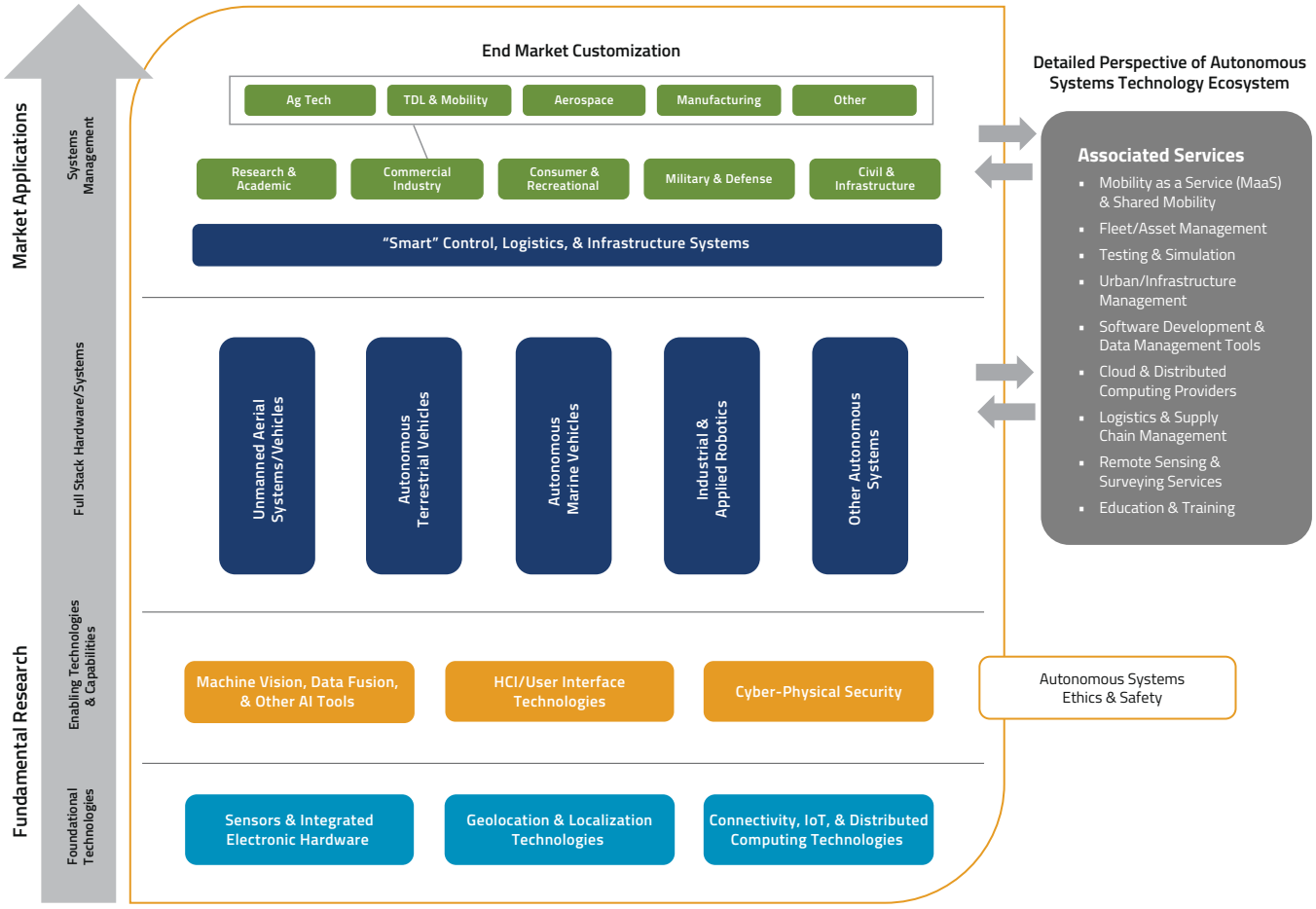
## Autonomous Mobile Systems:
## A Transformational Opportunity

Advancements in technology and the forces of convergence are impacting almost every industry and creating significant emerging growth opportunities. Some legacy industries are facing significant change as a result of new business models enabled by convergence of multiple technologies, while other entirely new industries are emerging. In one such area, multiple technology domains are converging to enable the development of Autonomous Vehicles (AVs) which have the potential to not only impact the characteristics of the vehicles themselves but create fundamental shifts in the future of mobility and the infrastructure that vehicles use and interface with. In recent years, major investments and prototyping efforts have focused public attention on this applications area and captured the imagination of industry and policymakers seeking to advance the next generation of technology-based industries.

While autonomous on-road vehicles are one of most publicized applications of autonomy (the ability of a machine to make decisions without the intervention of a human), they are only a part of a much wider landscape for autonomous mobile systems applications. Enabled by new technology convergence areas, significant change is coming to physical devices of any scale that both move and may be equipped with some form of sensing and decision-making system to intelligently perform tasks and navigate their environment. Many tasks that require human or machine spatial movement are potential prospects for automated mobile systems approaches, and this opens up vast and diverse market potentials for disruptive industries. **There is a large-scale economic development opportunity for regions of the country that have a distinctive position in the technologies and talent required to research, develop, and build complex integrated autonomous mobile systems products.** It is a very specialized space, however, and as Figure ES1 illustrates, the "full stack" of technologies needed to advance such products to prototyping and end market applications is quite complex.

To bring autonomous mobile systems solutions to market, it is not sufficient to build capacity in any one component of the technology stack. Rather, the goal of full deployment of autonomous end market solutions requires capabilities (or the ability to reliably source those capabilities) across the entire technology stack, as well as the means of linking the capabilities in each layer of the stack so that a system can perform as a fully integrated platform rather than a partial solution that requires further commercialization by others. **Regions who are able to build out their technology ecosystems to support this type of integration will be poised to realize major economic growth. Triangulating results from multiple recent market research reports places the terrestrial autonomous mobile systems market alone at an estimated $802 billion global market by 2025-26. When adding aerial, marine, and defense autonomous systems to capture the broader autonomous mobile systems market space context, the total likely climbs above $1 trillion in total market size during the mid- to late-period**

**FIGURE ES1.**
Autonomous Mobile Systems Stack




***Source:*** *TEConomy Partners.*

**of the present decade.** If a region with a robust and well-supported technology ecosystem were to capture even 1% of the $1 trillion global autonomous mobile systems market, it would equate to a $10 billion growth opportunity developing within the next decade.

The implications for potential economic growth around a rapidly scaling multi-billion dollar autonomous mobile systems industry, in conjunction with the readily apparent base of expertise and assets relevant to these technologies in Pittsburgh, have been recognized by key regional stakeholders. While those engaged in advanced economic development for the Pittsburgh region have observed the organic growth of the autonomy sector to date, the opportunity presenting itself to the region and the Commonwealth of Pennsylvania today is of such a scale and importance that a detailed examination of the opportunity is required that includes an evaluation of existing industry activity, current regional innovation assets that can be leveraged towards this opportunity, any gaps in the ecosystem that need to be addressed, and a resulting strategy and action plan developed to guide realization of the full economic opportunity as it unfolds.

# Reaching Critical Mass:
# The Profile of Pittsburgh's Autonomy Industry Today

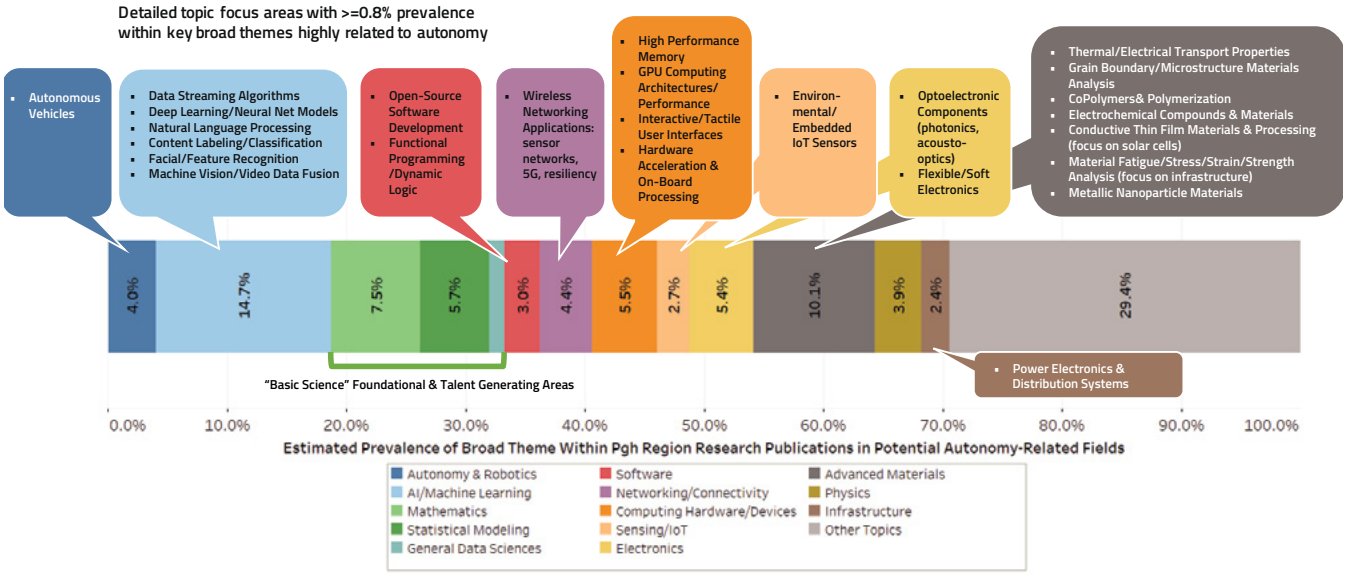
The Pittsburgh region has a long history of research leadership in software and robotics that, driven by its core academic research institutions, has evolved into a significant base of activity at the cutting edge of modern technology applications in areas like artificial intelligence (AI), machine perception, high performance computing, and autonomous systems. **Today, industry leaders, investors, and skilled talent agree that Pittsburgh represents one of the distinct hubs for autonomous systems activity in the country. Moreover, there is evidence that the regional ecosystem has reached an inflection point in developing a focus on mobile autonomous systems such that it has begun to drive an industry cluster of emerging and established companies that can serve as an economic development engine beyond supporting continued excellence in R&D.**

At the heart of the Pittsburgh region's innovation ecosystem is a broad base of academic research institutions that support translational research activity and produce highly skilled talent, anchored in particular by Carnegie Mellon University's global leadership in AI and robotics research. The strength of the academic research community in this regard is evidenced by the large-scale federal research funding coming to Pittsburgh to support robotics and associated fields. From 2015 to early 2021, combined grant funding received from the U.S. Department of Defense (DOD), National Science Foundation (NSF), the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA) was $162.9 million[1]. Particularly important is DOD funding, both in terms of the significant funding volume (over $115 million) and also because DOD activity spans a full-spectrum of integrated autonomy applications (driving research in fully autonomous air, ground, and space systems integration). These military focus areas drive research and innovation that translates well into commercial applications, in areas such as logistics and materials handling, agricultural and construction robotics, and human transportation.

The themes present in Pittsburgh's research across multiple indicators of research and innovation data (one of which, research publications activity, is shown in Figure ES2) represent a deep level of regional excellence in areas highly aligned with numerous elements of the autonomous systems technology stack. This represents a signature strength for Pittsburgh that positions it amongst the top ecosystems in the country in generating the technology and talent "push" that drives ideation and subsequent opportunities to commercialize innovative technologies.

1 Appendix E, Table E4.

**FIGURE ES2.**
## Identification of Pittsburgh Institutional Research Competencies Using Latent Topic Modeling and Research Publications Data




***Source:*** *TEConomy analysis of Clarivate Web of Science publications data*

**The region's excellence in fundamental research has in turn driven organic growth of a cohort of thought leaders focused on the autonomy industry which has expanded the cluster over the last decade to its current critical mass.** Often beginning as spinouts or founded by alumni affiliated with regional research institutions such as Carnegie Mellon and the University of Pittsburgh, several of these companies have grown to attract significant venture and direct corporate investments that have raised the region's profile in autonomous systems over the past five years. These efforts culminated in 2020 with multi-billion-dollar investments across several different Pittsburgh autonomous vehicles companies representing a significant milestone for the industry cluster's growth. The high-profile investments by leading original equipment manufacturers (OEMs) in a major autonomous systems end market have helped to firmly establish the region's reputation as a hub for the autonomous systems cluster and driven further attraction of strategic growth partners and skilled talent to the local ecosystem.

### Pittsburgh's Autonomous Vehicle Companies are Driving Major Investment in the Region

- **Argo AI has secured total investment from Ford and VW of $3.6B.**
- **In December of 2020, Aurora acquired Uber's self-driving ATG unit. The company also recently announced its plans to go public with a pre-transaction equity value of $11 billion.**
- **First announced in March 2020, Motional was formed as joint partnership between Aptiv and Hyundai with major employment presence in Pittsburgh as a result of acquiring a Carnegie Mellon spinout.**

It is also notable that the research ecosystem demonstrates a highly favorable fluidity, whereby people and knowledge are transferring between industry and the universities and vice versa. This flexible interface between the corporate and academic R&D and innovation communities is highly valuable, maintaining up-to-date understanding of the capabilities, advancements,

innovations, and trends on both sides, and sustaining robust pathways for talent to maximize their contributions to sector advancement. Such symbiosis between academe and industry is rare and represents a distinctive characteristic of the Pittsburgh autonomous mobile systems ecosystem.

**Even though the region's growth in autonomous vehicles has received most of the national attention, Pittsburgh hosts a much broader set of companies focused on nearly every end market application for autonomous systems.** As shown in Figures ES3 and ES4, not only does the current set of companies demonstrate a focus on deployment into multiple markets (which have further specialized applications within specific industries), but within those markets they are integrating and deploying multiple elements of the technology stack ranging from electronic components and software to full systems. Representing just a small set of the complete base of industry activity thriving in this ecosystem outside of the autonomous vehicles market, other applications areas include scaling local businesses in autonomous mobile robotics (AMR) systems, industrial and logistics automation solutions, autonomous inspection and imaging platforms, autonomous construction systems, and intelligent mobile manipulation solutions.

## FIGURE ES3.
## Estimated Current Employment at Autonomous Systems Companies in Pittsburgh, by Technologies Deployed and Markets Served*

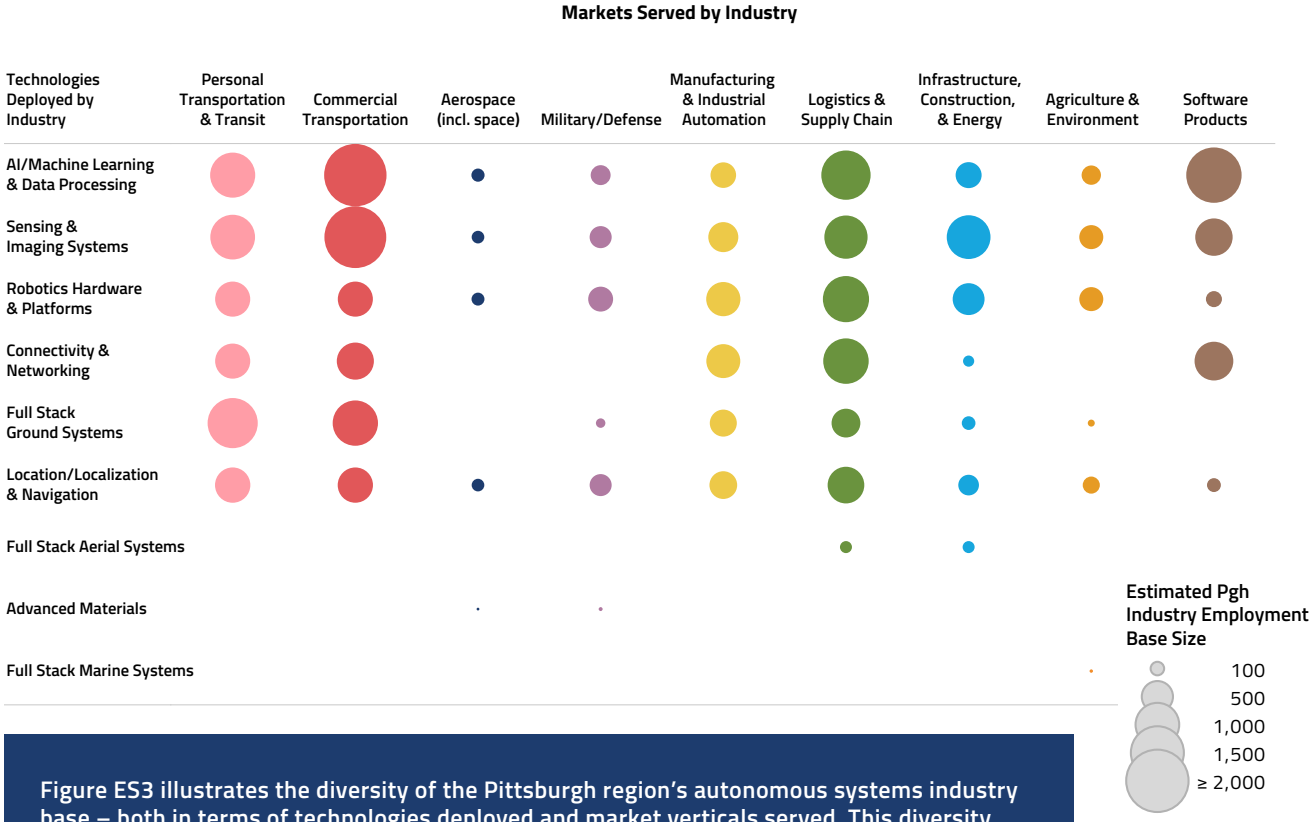
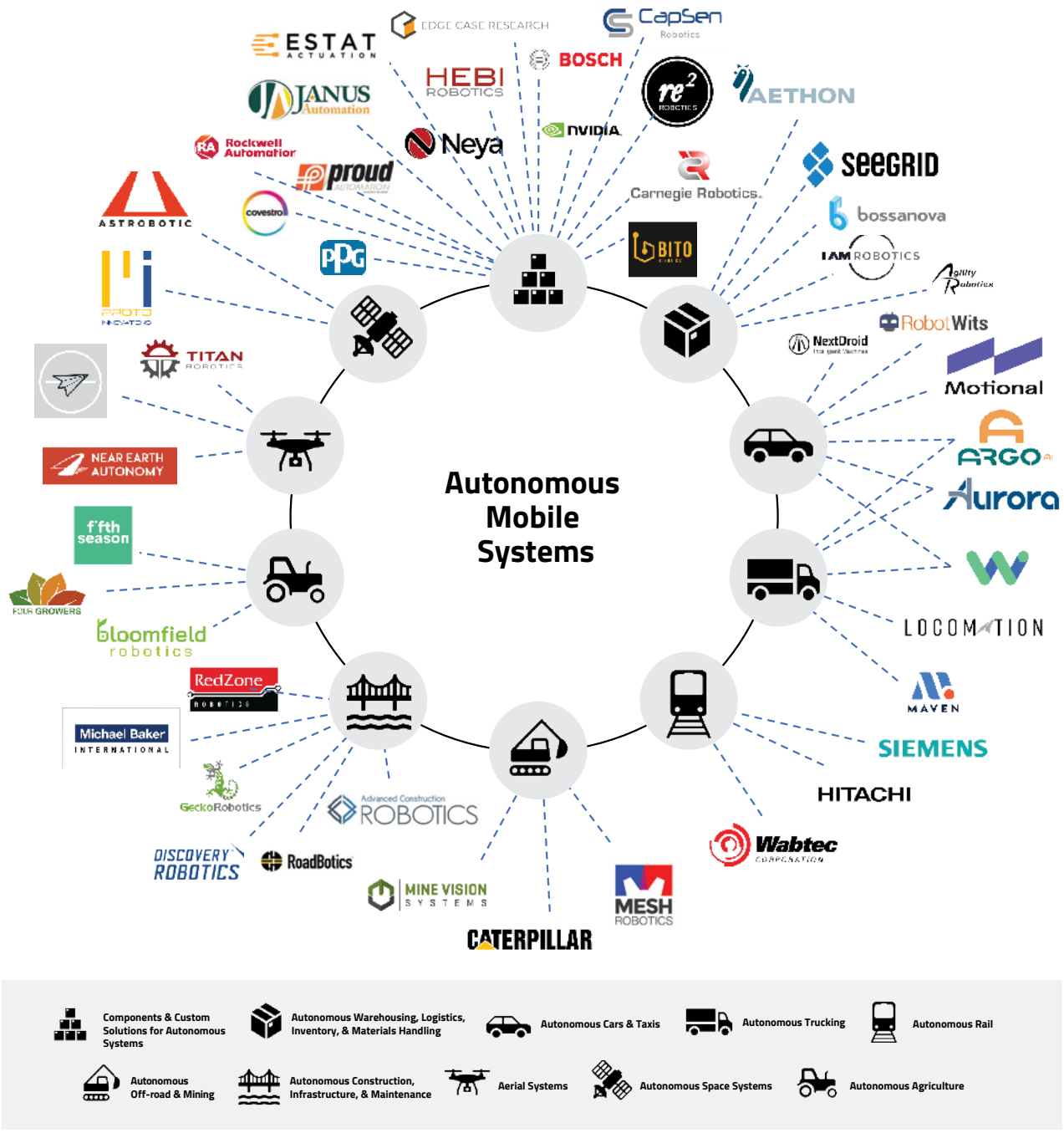



Figure ES3 illustrates the diversity of the Pittsburgh region's autonomous systems industry base – both in terms of technologies deployed and market verticals served. This diversity, spreads risk and provides multiple potential pathways to ongoing industry growth.

***Note:** companies may deploy multiple technologies and serve multiple end markets as a part of their business activity*

***Source:** TEConomy analysis of Pitchbook VC, SBIR, USPTO, company LinkedIn profile, and other data*

**FIGURE ES4.**
Examples of the Diverse Base of Companies Operating in Autonomous Mobile Systems Verticals Within the Pittsburgh Ecosystem



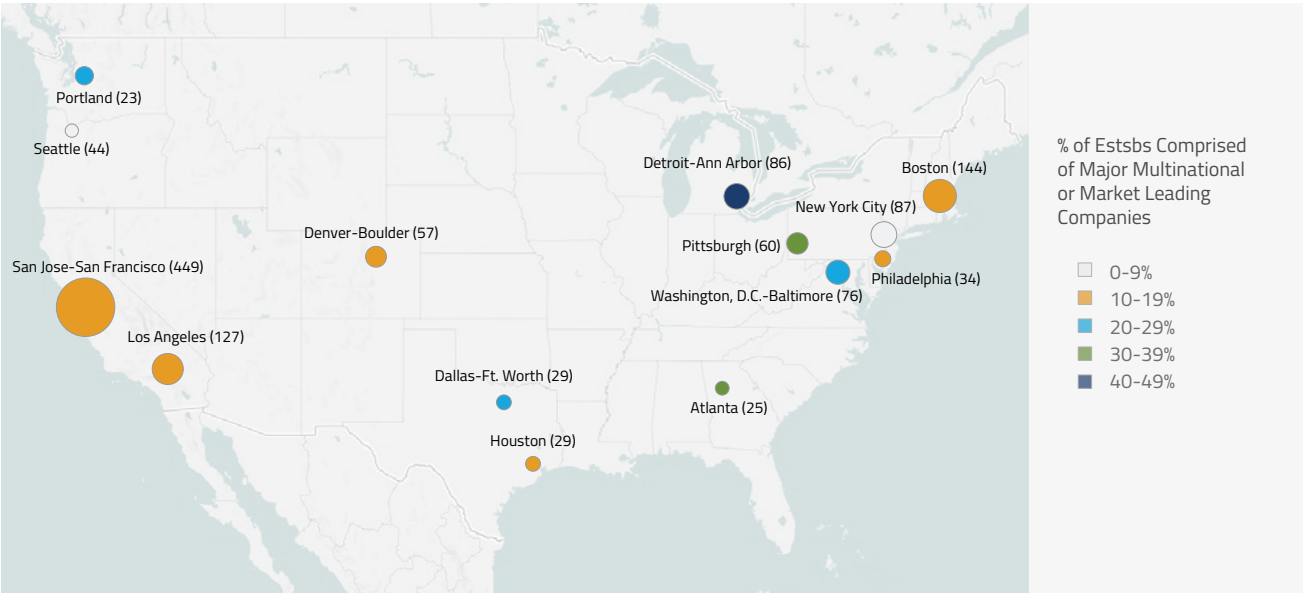

Relative to other locations with significant business establishments focused on the autonomous systems industry, this diversity stands out as a key competitive strength that can help the region remain agile to shifts in broader markets as adoption of autonomy solutions grows.

# An Emerging Competitive Landscape:
## The Need for Bold Action to Secure Pittsburgh's Position

Growing alongside the Pittsburgh region's industry and innovation presence, a broader global market for autonomous systems anchored by other regional innovation hubs has also emerged. **Within the U.S., states and regions are taking action to position themselves to be at the forefront of emerging technologies and market applications associated with the industry sector. Coupled with broad uncertainties about the exact pathway and timing to mass deployment of autonomous solutions within various end market verticals, the outlook for Pittsburgh's future within this increasingly competitive space is far from assured if the region takes a passive stance and relies solely on existing industry and innovation activities.**

As an emerging, R&D intensive industry that does not yet have widely productized goods and services or large volume consumer bases, the broader landscape of the autonomous systems industry is often difficult to fully characterize. However, the footprint of national mobile autonomous systems companies and their key supplier and supporting service companies (see Figure ES5) reveals the **Pittsburgh region's autonomous systems industry is hardly alone amongst a growing base of geographic regions who have their own expanding industry clusters.** This highlights the trend towards an increasingly competitive market landscape, with other regions seeking to build or expand their own industry bases to take advantage of new opportunities in autonomy deployment applications.

**FIGURE ES5.**
**Distribution of U.S. Autonomous Systems Industry Establishments, Combined Statistical Areas with 20 or more Establishments**




***Source:*** *TEConomy analysis of BCC and IBISWorld Market Research, Pitchbook VC data, SBIR data, and AUVSI unmanned systems database.*

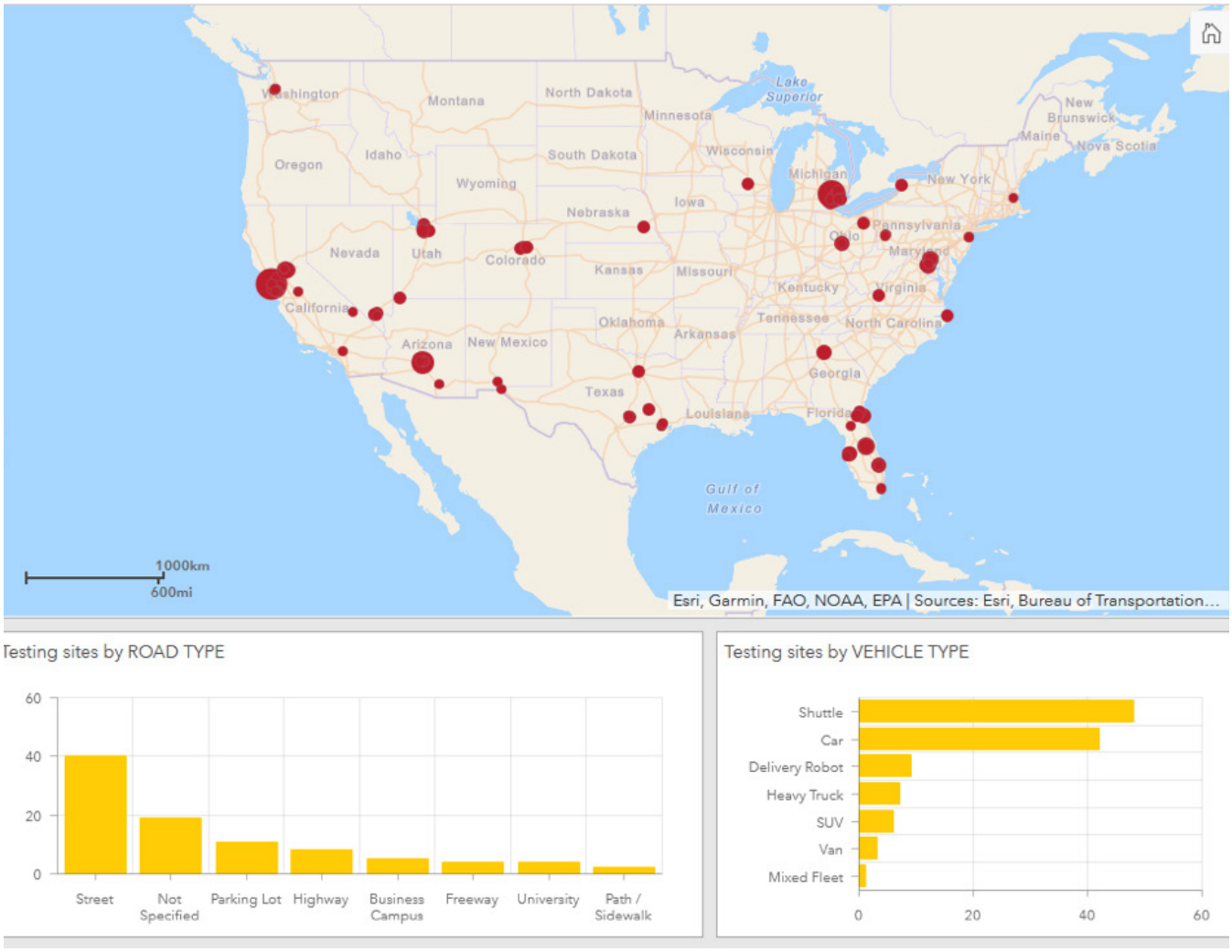
As the autonomous systems industry continues to expand nationally, **states are increasingly undertaking economic development and public policy actions to position themselves to capture market share.** Much of this activity is focused on policies that enable testing of autonomous systems within states as well as sources of funding for demonstration and infrastructure projects that incorporate autonomous solutions as a part of their efforts. This is most evident in state

policymaking related to autonomous vehicles testing which has greatly expanded since 2013, where according to the National Conference of State Legislatures (NCSL):

> *Between 2013 and 2020, 31 states and the District of Columbia enacted legislation related to autonomous vehicles, governors in 11 states issued executive orders, and 5 states both issued an executive order and enacted legislation."*

T**he results of state action are starting to be realized through the attraction of autonomous systems testing efforts to regions across the country as companies continue to advance their platforms.** In the autonomous vehicles sector alone, the distribution of autonomous vehicle testing sites reported by industry (seen in Figure ES6) spans not only the major research and industry hubs in this sector, but also many additional states that have the appropriate environmental and regulatory conditions that are attractive to companies.

**FIGURE ES6.**
## Autonomous Vehicle Testing Sites Reported to NHTSA AV TEST Initiative




***Source:*** *NHTSA AV TEST Tracking Tool*

*Pictured here is Aurora's fleet of vehicles. The Aurora Driver has been designed to be deployed across different vehicle types, be it a sedan, a van, or a Class 8 truck.*

**As states have primarily focused on the regulatory and testing landscape for autonomous systems, several regions and cities have simultaneously been making significant investments in establishing or expanding innovation ecosystems that support the autonomy technology stack to help drive their ability to capture market share.** In order to boost their ability to attract and retain companies, talent, and investment capital, regions with significant autonomous systems industry presence across the U.S. are building programmatic efforts and other infrastructure that support their innovation ecosystems (see text box). **Pittsburgh will face increasing competition from regions with signature state and regional initiatives that support autonomous systems applications and must establish its own programs to reinforce its current innovation ecosystem as well as root emerging companies and talent in the region.**

In the midst of this changing national landscape, discussion with Pittsburgh's industry leaders and economic development stakeholders in this space identified several common themes that outline the risks and threats that Pittsburgh must navigate in order to realize long term success in growing the industry as a regional economic driver. Key industry and ecosystem trends raised in stakeholder discussions included:

## Examples of Regional Programmatic Efforts to Support Autonomous Systems Innovation Ecosystems

- **Silicon Valley Robotics (SVR)** is a membership-driven coalition of robotics companies clustered in northern California.
- **Mass Robotics** functions as a cluster-development organization organized around a purpose-built business incubator featuring a collection of specialized prototyping and testing facilities aimed at startups in robotics and connected devices.
- **DriveOhio** is a formalized consortium of state agencies involved in "smart mobility," managed through an office of the Ohio Department of Transportation (ODOT) and able to contract under the latter's authority. Through DriveOhio, the ODOT and JobsOhio committed $45 million to a new Smart Mobility Advanced Research Center (SMART Center), an automated and connected vehicle-testing facility.
- **Mcity** is a test facility combined with an industry-sponsored research program created in 2014, all housed at the University of Michigan at a 32-acre artificial urban/suburban setting equipped with 5G vehicle-to-everything service and other advanced testing technologies. Mcity claims a cumulative total of $26.5 million invested since 2015 in R&D and deployment projects, with approximately 20 active research projects that pool funds from industry sponsors.

## The Impact of Pittsburgh's Autonomous Systems Industry Cluster

A conservative estimate of the Pittsburgh region's autonomous systems industry today includes **71 companies and 6,300 jobs which generate significant economic impacts.**

- These direct jobs support more than 8,600 additional jobs through indirect and induced effects, for a total economic impact of over 14,900 jobs.
- These jobs support almost $651 million in estimated direct labor income, and $1.2 billion in total labor income.
- The industry generates an estimated $1.5 billion in direct economic output and supports nearly $3 billion in total economic output.
- The industry generates over $161 million in direct local, state, and federal tax revenues and nearly $347 million in total tax revenues.
- One employee in the autonomous systems industry sector supports approximately 2.36 additional employees in other industry sectors.

- Acknowledgement that the nascent industry will still be highly influenced by broader market headwinds.
- Concern that the state does not display a best practice regulatory and operating environment necessary to enable industry investment and growth, particularly for the autonomous vehicle industry.
- Concern that the region may risk being viewed as an "R&D outpost" for major companies rather than a headquarters destination.
- Recognition that significant portions of the components supply chain for autonomous systems are offshore.
- Current regional ecosystem organizations that are generally aware of the potential of this market space and supportive of tech-based entrepreneurial activity in autonomy, but that have programs and initiatives which are too diffuse and not focused at scale on this vertical.
- A perception that local venture funding gaps persist despite the autonomy industry's success in attracting investment from outside the region.
- Concern that the talent supply base of the region is facing skill gaps and other growing pains in the wake of the success of the initial cohort of autonomous vehicles companies.

These issues will require bold, forward-thinking action to mitigate the risks to future growth and reinforce Pittsburgh's position as a national leader, which could drive decades of future economic growth for the area once products reach mass deployment.

In the face of an emerging competitive landscape seeking to capitalize on the next phase of autonomous systems industry growth, the stakes are high for Pittsburgh's current industry base and the significant economic output it provides currently and promises for

the future. To illustrate the value the industry provides to the Pittsburgh region today, TEConomy analyzed the economic impact of 71 local firms (or in cases of major multinational corporations, divisions, or operating units of those firms) that were identified as having core business operations that primarily served the autonomous systems industry. **The estimated direct employment footprint of Pittsburgh's autonomous systems firms totals over 6,300 jobs which provide an estimated $651 million in labor income, $34.7 million in state and local tax revenues, and $126.7 million in federal tax revenues. These companies generated a further 8,604 full or part time jobs through indirect and induced effects to support a total of 14,923 jobs in the region.**

The total employment impacts described above are being generated by an industry sector that is still maturing and largely in pre-revenue stages for many of Pittsburgh's companies, including large employers in the autonomous vehicles space. The potential impact for the region as the industry continues to grow could scale exponentially in the coming decades, but only if Pittsburgh can continue to generate innovative companies advancing autonomous systems solutions, retain large industry employers and act as a site for their expanding testing operations, and provide an advantageous location for autonomous systems companies to grow their employment in manufacturing, business support, and other administrative and service functions as they expand in the course of products reaching widespread deployment.

To illustrate this point, consider just the market segment focused on autonomous vehicles. A 2019 study by the Boston Consulting Group and the Detroit Mobility Lab[2] estimates that the smart mobility market will generate 85,000 new U.S. jobs in autonomous vehicles and 7,000 U.S. jobs in smart-road infrastructure by 2028 across engineering, computer-related, and skilled trades occupations. **If the Pittsburgh region maintains its current market share and innovation ecosystem but does not take significant action to improve its competitive position it may be able to continue to grow organically but is not likely to attract a significant share of these new jobs that can accelerate the growth of the cluster beyond its current R&D-focused employment footprint. In the face of competition from other states for these new jobs, the majority of which do not require proximity to universities and labs to perform operations and support services-oriented functions within the AV industry, there is no guarantee that Pittsburgh will be the primary destination for ongoing growth as AV companies seek to find attractive environments to site their new business functions. As the BCG and Detroit Mobility Lab study notes:**

> *"If they are serious about creating or expanding as mobility hubs to boost the local economy, cities and states must be willing to become the main orchestrators of the environments they want to create. They must collaborate with academic institutions to support educational and training programs. They must be open to working with companies that are looking for incentives, such as tax breaks, to move into the area, and help companies navigate regulations governing testing, safety, certifications, and AV operations. They should also clear the way for the creation of testing grounds where car companies can try out new vehicles. Finally, they must offer the social, cultural, and recreational amenities that prospective students and people with in-demand skills want in the area where they work and live."*

These conclusions are equally applicable across the various sectors of the broader mobile autonomous systems sector and highlight the return on investment that proactive regions can expect to realize if they commit to supporting the growth of this industry.

2 "The US Mobility Industry's Great Talent Hunt", *Boston Consulting Group and Detroit Mobility Lab*, 2019

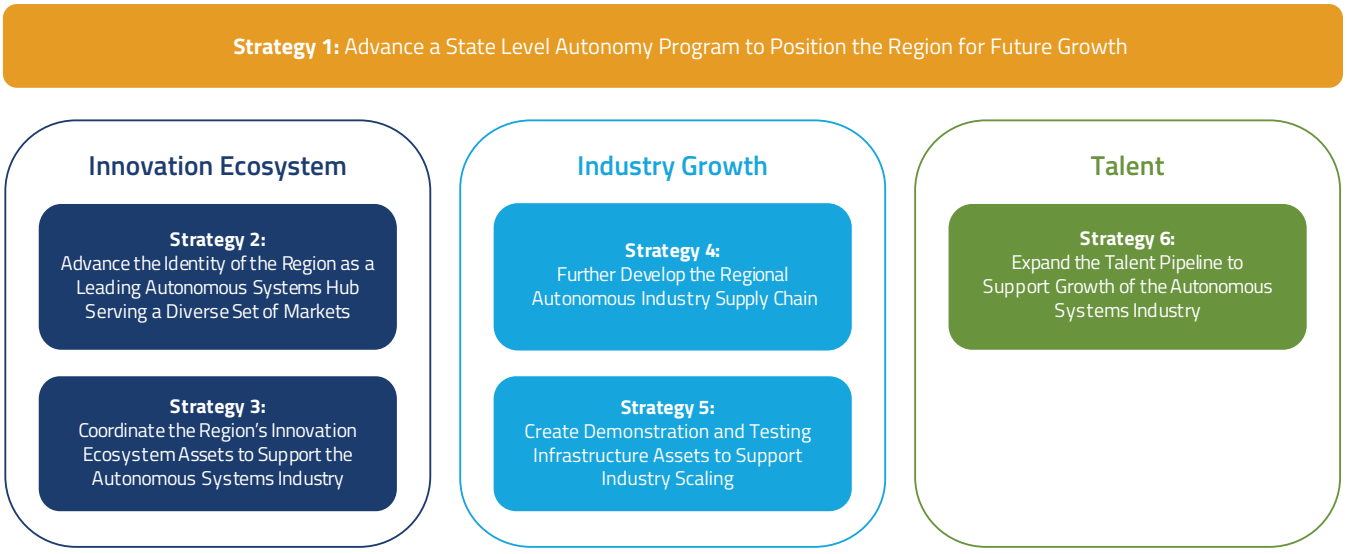
# Realizing the Vision:
# A Strategic Plan for Growing Pittsburgh's Autonomous Systems Industry

**Pittsburgh's regional position in autonomous mobile systems can be significantly strengthened by taking bold action to invest in the opportunities presented by this cluster. Multiple strategies and actions must be implemented in a coordinated, high-commitment effort to build and sustain the complete ecosystem needed to secure Pittsburgh's leadership position and stay ahead of the competition. Actions are needed to rapidly evolve the opportunity from being predominantly R&D focused, to a diverse, full-range industry cluster that spans development of innovative new technologies all the way through the commercialization cycle of manufacturing, distribution, and service of high value products and services.**

TEConomy has proposed a strategic plan that comprises six strategies and an associated set of 16 actions purpose-designed to optimize the regional ecosystem for autonomous mobile systems and catalyze substantial economic growth. The strategic plan has been developed based on multiple avenues of analysis and input received across the project from a wide set of public and private stakeholders. While it is prescriptive and actionable, it is also structured to have flexibility in terms of being adaptable and evolvable given that the trajectory and growth curve of various sectors, particularly in terms of timing of market acceptance and regulatory approvals is as yet indeterminate and subject to change. Because this is anticipated to be a fast-moving opportunity, the strategy is intended for implementation over a two- to three-year timescale (with recognition that some actions, such as expanding graduate output, are inherently more long-term in their realization).

The recommended strategies are shown on Figure ES7, indicating the crosscutting nature of advancing state support, and the general classification of each strategy by theme. The recommended actions associated with each strategy are summarized on Figure ES8. Detailed descriptions of each strategy and action are provided in Section IV of the full report.

**FIGURE ES7.**
Strategies for Growing Pittsburgh's Autonomous Mobile Systems Industry



## FIGURE ES8.
## Recommended Actions Associated with Strategies for Growing Pittsburgh's Autonomous Mobile Systems Industry

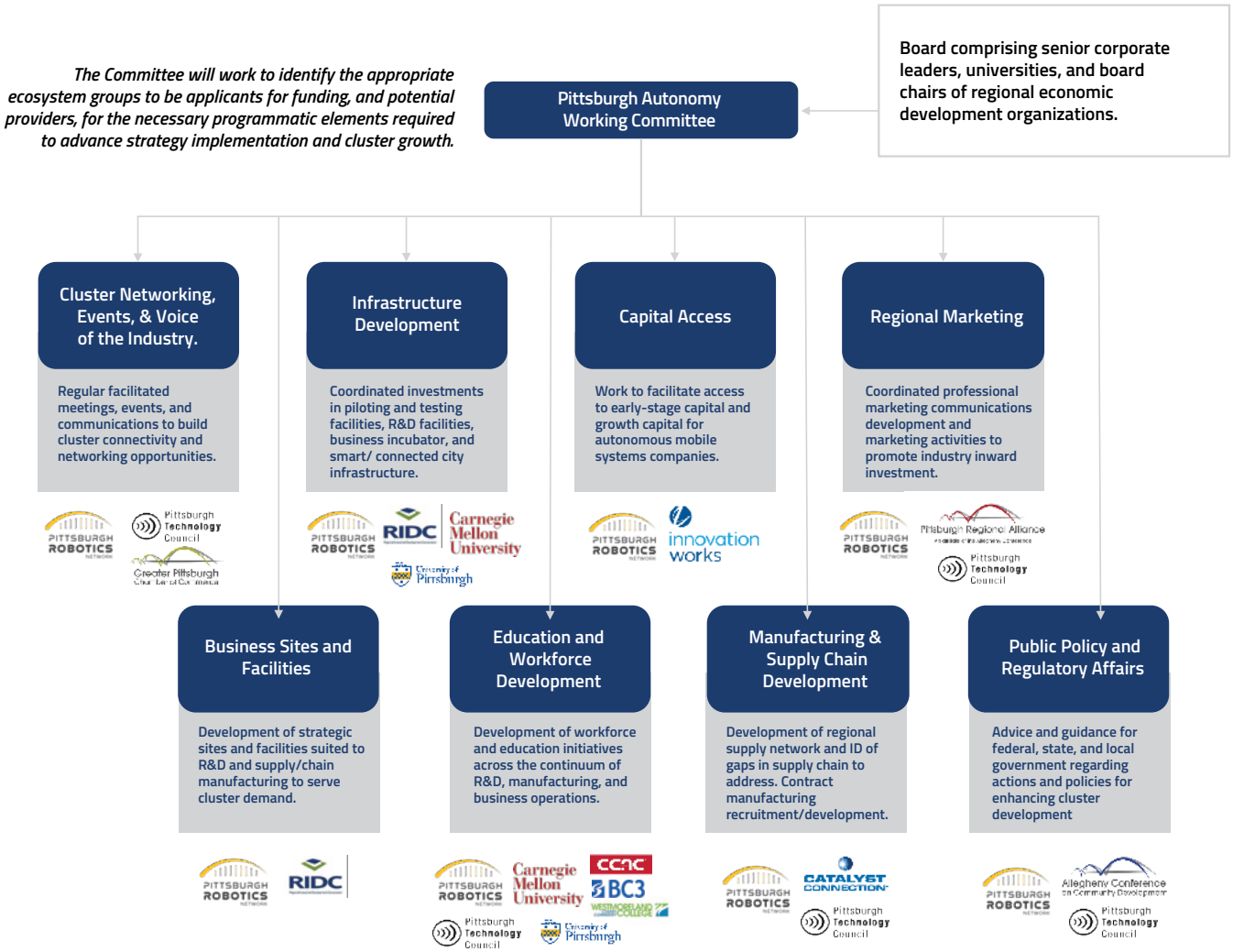
| | |
|---|---|
| **Strategy 1:** Advance a State Level Autonomy Program to Position the Region for Future Growth | **Action 1.1:** Develop and advance a framework for a signature state initiative in autonomy<br>**Action 1.2:** Take a proactive stance in developing forward-thinking regulatory guidance for policymakers<br>**Action 1.3:** Advance public-private smart infrastructure projects that support autonomous systems deployment |
| **Strategy 2:** Advance the Identity of the Region as a Leading Autonomous Systems Hub Serving a Diverse Set of Markets | **Action 2.1:** Develop a branding and marketing initiative that can increase both external and internal public awareness<br>**Action 2.2:** Develop a business attraction initiative targeting scaling and mid-size companies in the technology stack<br>**Action 2.3:** Attract several leading trade shows, conferences, and other high-profile showcase events |
| **Strategy 3:** Coordinate the Region's Innovation Ecosystem Assets to Support the Autonomous Systems Industry | **Action 3.1:** Support a dedicated organization that can be the nexus for regional innovation and cluster development activity in autonomous systems<br>**Action 3.2**: Address risk capital stack gaps<br>**Action 3.3**: Enhance regional support mechanisms for autonomy industry entrepreneurs |
| **Strategy 4:** Further Develop the Regional Autonomous Industry Supply Chain | **Action 4.1:** Build out a contract manufacturing and regional supply chain consortium<br>**Action 4.2:** Identify shared, noncompetitive, technology areas for collaborative industry projects and attraction of supply base |
| **Strategy 5:** Create Demonstration and Testing Infrastructure Assets to Support Industry Scaling | **Action 5.1:** Explore the potential for shared testing and demonstration projects that can serve as industry assets<br>**Action 5.2:** Implement a set of ongoing, public-facing autonomous systems demonstration projects |
| **Strategy 6:** Expand the Talent Pipeline to Support Growth of the Autonomous Systems Industry | **Action 6.1**: Expand the talent pipeline through coordination across regional institutions<br>**Action 6.2:** Address current gaps in the region's autonomy industry talent base |

The Pittsburgh region benefits from having a broad range of experienced economic development-focused organizations that provide quite robust coverage of key innovation- and technology-based economic development services. Some of these services are specific, or have elements tailored to, the robotics and autonomous systems sectors, while others are more cross-cutting, available to service companies in most innovation sectors. The one organization that is 100% focused on the robotics and autonomous systems space is Pittsburgh Robotics Network (PRN), which is a relatively new and growing industry-led organization representing the sector.

Advancing the full strategic plan outlined herein will require significant governance oversight, since implementation will require the management and allocation of large-scale funds. With substantial funding likely to be sought from public entities, including the Commonwealth of Pennsylvania and the U.S. Federal Government (through EDA, DOT programs, etc.), together with philanthropic donations, there is a need to establish an oversight organization with the appropriate IRS designation and fiduciary protections required for the management, regulatory reporting, and disbursement of programmatic funding. As a placeholder name for the proposed organization, this document uses the "Pittsburgh Autonomy Working Committee" as a temporary descriptor. The Pittsburgh Autonomy Working Committee" is recommended not as a service provider nor a trade association, but rather the keepers of the cluster development strategy and evaluation arm that governs the expenditure of funds and their impacts.

The Working Committee may be organized with a fiscal agent and operate as an initiative rather than a staffed organization. As envisioned the Working Committee will be managed by a high level board comprising Presidents or CEO's of regional autonomous mobile systems companies, leadership of research universities, and the board chairs of primary ecosystem non-profit economic development organizations. The Working Committee would be responsible for supervising the implementation of the strategy and will seek proposals from ecosystem organizations to provide services in key functional aspects of strategy and action implementation. Figure ES9 shows this conceptual structure, the key categories of ecosystem functions needing to be addressed, and key examples of organizations that would likely be applicants and potential providers for the necessary programmatic elements.

**FIGURE ES9.**
## Potential Leadership for Strategy Implementation and Ecosystem Organizations to Engage




Autonomous mobile systems will represent a fast emerging $1 trillion global industry opportunity by 2025/26, and Pittsburgh's robust core competencies positions it well to be a major participant in this transformational economic opportunity. Realizing this full potential, however, requires addressing some of the shortfalls and gaps in the regional ecosystem, coordinating strategies and actions designed to optimize the regional autonomy environment and supporting ecosystem for competitive success. Addressing these needs requires investment of both dollars and human capital across the multiple strategies and actions outlined herein.

To place some bounds around the likely level of investments needed, an initial budget estimation has been prepared covering each of the strategies and actions (Table ES1). In total, it is estimated that full strategy and action plan implementation will require approximately $154 million, with the Commonwealth of Pennsylvania funding 36.4% ($56 million), the Federal Government 13% ($20 million), and regional or local resources funding 50.6% ($78 million). The resources required to implement these strategies will build on the billions in corporate and institutional research investments that have already been made in Pittsburgh region.

## TABLE ES1.
### Anticipated Funding Requirements for Strategy Implementation[3]

| Strategies | Commonwealth Funding | Federal Funding | Regional Funding | Notes |
|---|---|---|---|---|
| **Strategy 1:** Advance a State Level Autonomy Program to Position the Region for Future Growth | $53,250,000 | $17,500,000 | $24,750,000 | Includes investment in test and demonstration infrastructure, business incubator, geofenced demonstration corridors, smart city infrastructure, incentives for attracting contract manufacturing, and operational support funding for PRN. |
| **Strategy 2:** Advance the Identity of the Region as a Leading Autonomous Systems Hub Serving a Diverse Set of Markets | $0 | $0 | $800,000 | Includes development of branding and marketing initiative and collateral materials, business attraction activities, and attraction of cluster focused conferences/events. |
| **Strategy 3:** Coordinate the Region's Innovation Ecosystem Assets to Support the Autonomous Systems Industry | $0 | $0 | $50,250,000 | Includes $50 million venture capital fund and grant funding support for entrepreneurship programs. |
| **Strategy 4:** Further Develop the Regional Autonomous Industry Supply Chain | $1,000,000 | $1,000,000 | $500,000 | Major $'s required for this strategy are captured under Strategy 1. Includes building regional supply network, attraction of contract manufacturing, and ID of shared development initiatives. |
| **Strategy 5:** Create Demonstration and Testing Infrastructure Assets to Support Industry Scaling | $1,000,000 | $1,000,000 | $1,000,000 | Major $'s required for this strategy are captured under Strategy 1. Implementing a set of ongoing, public-facing autonomous systems demonstration projects. |
| **Strategy 6:** Expand the Talent Pipeline to Support Growth of the Autonomous Systems Industry | $750,000 | $500,000 | $1,000,000 | Coordination of workforce and education initiatives across the continuum of R&D, manufacturing, and business operations. |
| | **State $56,000,000** | **Federal $20,000,000** | **Regional/Local $78,300,000** | **Combined Total $154,300,000** |

The recommended additional strategic investment profiled on Table ES-1 will have a compounding effect on the deep investments already made or committed within the sector by leading regional organizations, philanthropies, universities, companies, and investors. It will be central in enabling the next level of growth in the cluster to occur, whereby R&D innovations will further translate into on-the-ground manufactured technologies and innovative business growth. The autonomous mobile systems and robotics ecosystem in the Pittsburgh region has experienced intensive recent investment in research and development infrastructure – with

3 Further detail on funding estimates is provided in Chapter IV. Numbers are approximations based on costings of similar programs and initiatives nationally and budgets of example initiatives working in cluster based program advancements in other states and regions.

particularly robust investment taking place in R&D at Carnegie Mellon University, investment that, importantly, demonstrates a focus on applied research and engagement with industry. Table ES-2 summarizes recent signature investments relevant to the sector in the Pittsburgh region, showing **investment exceeding $490 million.** The strategies and actions outlined in this report are designed to build upon these existing investments, with additional public-private investments that strategically reinforce the ecosystem so that it may realize the full commercial promise of a fast growing, transformational industry sector.

**TABLE ES-2.**
**Recent Investments of Relevance to the Expansion of the Pittsburgh Autonomous Mobile Systems Ecosystem**

| Investment | Estimated Amount | Notes |
|---|---|---|
| Advanced Robotics for Manufacturing (ARM) Institute | $250 million | ARM funded by the Department of Defense and catalyzed by Carnegie Mellon. Both ARM and MFI (Manufacturing Futures Initiative at Mill 19), an interdisciplinary research initiative, were launched with the help of a $20 million gift from the Richard King Mellon Foundation, which provided significant support for research and the new Mill 19 facility. |
| RK Mellon Grant to Carnegie Mellon University | $150 million | $75 million for new science building on the Carnegie Mellon campus in Oakland, and $75 million for the robotics innovation center and an institute focused on advanced materials and manufacturing at Hazelwood Green. |
| Corporate Test Track Investments | >$50M | Over $50M in private investment commitment focused on testing facilities, tracks, and associated infrastructure. |
| Carnegie Mellon University-CCDC Army Research Laboratory Cooperative Agreement | $25 million | Carnegie Mellon University and the U.S. Army Combat Capabilities Development Command's (CCDC) Army Research Laboratory (ARL) have entered into a $3.5 million cooperative agreement that supports machine learning-enabled additive manufacturing to enhance the expeditionary manufacturing capability of the Army. The funding marks the beginning of a five-year program, led by CMU's College of Engineering, with the Army awarding up to four years and totaling as much as $25 million. |
| Argo AI Center for Autonomous Vehicle Research at Carnegie Mellon University | $15 million | A five-year, $15 million sponsored research partnership funding research into advanced perception and next-generation decision-making algorithms for autonomous vehicles. |
| US DOT Grant to HERL at the University of Pittsburgh | $1M | U.S. Department of Transportation awarded $1 million to the Human Engineering Research Laboratories (HERL) at the University of Pittsburgh, for a study of how automated vehicles can help people with disabilities. |
| RK Mellon Job Training & Career Readiness Grants | $250,000 + $125,000 | Advanced Robotics for Manufacturing Institute - $250,000 for the Keystone Space Collaborative. And, StartUptown - $125,000 to support the Pittsburgh Robotics Network's work to build a robotics industry cluster network of highly engaged stakeholders to fosters business growth and talent development. |
| RK Mellon Grant to Pittsburgh Robotics Network | $125,000 | June 2021 grant of $125,000 to support the continued growth of the Pittsburgh Robotics Network. |
| **Total** | **$491.5 million** | |

# Conclusion

An opportunity of this magnitude – an opportunity to lead in a fast growth technology sector and advanced industry – presents itself very rarely, and it has the potential to advance the region and state's economic development for decades to come. Public and private sector stakeholders in the region and the Commonwealth of Pennsylvania must act and invest with urgency and purpose to capture the full potential represented by this dynamic sector for transformative economic growth.


# I. INTRODUCTION

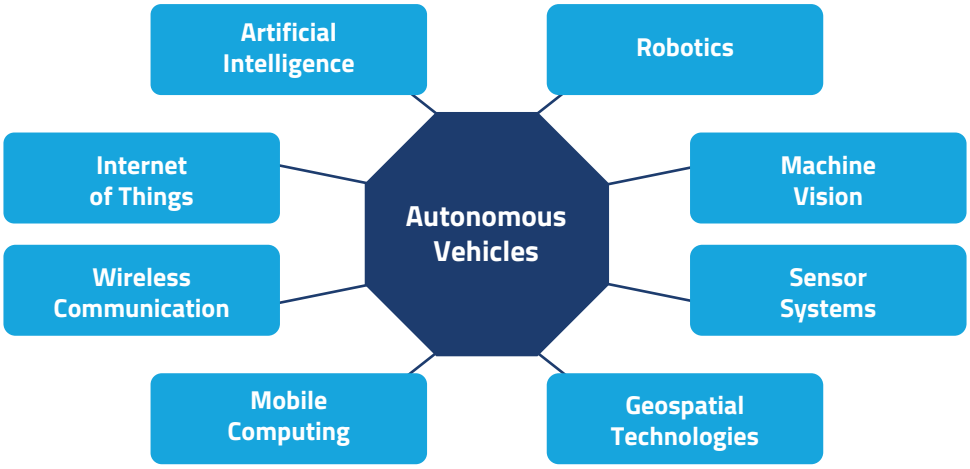
**Mobile autonomous systems represent a fast-emerging global market, likely to grow to over $1 trillion over the coming decade. This presents powerful growth opportunities for those regions that have specialized innovation capabilities in the multiple complex technologies that converge within the sector. This emerging industry opportunity, which includes autonomous vehicles and autonomous mobile robotics platforms, has every indication of being transformational for the economies of those regions able to establish and cement a leadership position.**

A state or regional economy, indeed any economy, is inherently dynamic—subject to change through both internal and external forces. Internal forces, such as R&D and innovation, work to introduce new products, improve existing products, and enhance the efficiency of their production and distribution. External forces, such as the actions of competitors or changing market preferences and demands, also contribute greatly to the dynamics of economic sectors. The overarching theme is one of "change" and it is an ongoing challenge for businesses (and, more broadly, for all leaders in society concerned with the performance of the economy) to identify changes on the horizon that may represent opportunities to leverage or challenges to address.

Technological innovation is a core driving force behind much of the change occurring across the economy, and digital technologies are a particularly robust agent of change. At the same time, in both science and industry, the phenomenon of convergence —whereby multiple disciplines and technologies come together to advance innovative new fields, technologies, and applications — has risen in importance

While advancements in technology, and the forces of convergence, are impacting almost every industry, some industries are facing particularly profound change as a result of new business models enabled by convergence of multiple technologies. The motor-vehicle, or automotive, industry is among the industries experiencing the early stages of a large-scale business revolution attributable to converging advanced technologies. Advancements in electric vehicles, provide an early example of disruptive technology impacting the automotive sector. Internal combustion engines and automotive transmissions are not required in an electric car – and efficient electric motors, and batteries with high energy storage density, are creating a revolutionary change in major components of vehicles and, therefore, their supply chain. While electric vehicles, and other alternatively fueled vehicles, are part of a disruptive technology revolution impacting the automotive sector, **another area of technology convergence has far more profound implications for the future of the industry.** Multiple technology domains (Figure 1) are converging to enable the development of Autonomous Vehicles (AVs) which have the potential to not only impact the characteristics of the vehicles themselves but create fundamental shifts in the future of mobility and the infrastructure that vehicles use and interface with.

**FIGURE 1.**
Examples of Technology Domains Converging to Enable Autonomous Vehicles and Mobile Systems




**Autonomous on-road vehicles (e.g. cars and trucks) are a much discussed application of autonomy** (the ability of a machine to make decisions without the intervention of a human), **but they are only a part of a much wider application and opportunity universe for autonomous mobile systems.** The technologies that converge to make an autonomous car or truck a reality, also see application across an extremely diverse range of additional uses. Systems for autonomously moving people (cars, public transit, etc.) are part of the opportunity, but so too are the movement of goods, the movement of parts and products in warehouses and manufacturing plants, the movement of minerals and bulk materials in mining, and multiple task-focused operations in agriculture, forestry, construction, municipal services, and a broad-range of other endeavors that require equipment to be mobile. In reality, large-scale change is coming to **physical devices of any scale that both move and may be equipped with some form of sensing and decision-making system to intelligently perform tasks and navigate their environment.** Tasks that require human or machine spatial movement are potential prospects for automated mobile systems approaches, and this opens up vast and diverse market potentials for the few places (so far) that have the very specialized R&D talent and technology integration knowhow required to advance such complex, multi-faceted technologies.

### A Digital Sector

While an autonomous vehicle or mobile device itself may be the most visible "product" of a new autonomous mobile systems industry, as Figure 1 shows, it is largely digital technologies that converge to make autonomous operations possible. This gives rise to the question of whether locations (regions) that have robust core competencies and a leadership position in these digital technologies may become the key hubs for this new industry sector and realize significant economic development rooted in autonomous systems industry growth.

When a disruptive technology revolution occurs within an industry the disruption may be profound enough to engender change in its spatial (geographic) footprint. Locations that may have dominated in the production of traditional industry products may not be the locations where the revolutionary new products are innovated and built. Opportunities arise for regions that contribute technologies that are converging in the new product to become key hubs for the industry's next evolution. This is likely to be the case in autonomous mobile systems, because the traditional locations that designed and manufactured products such as cars, heavy trucks, fork-lift trucks, agricultural tractors, construction vehicles, etc. may well not be locations

with the tacit knowledge and know-how, and the R&D core competencies, required to advance technologies that are at the core of autonomous mobile systems – primarily robotics, machine sensing, artificial intelligence, and associated software and systems integration capabilities.

## An Extremely Large-Scale Opportunity

We can predict that the places that have core competencies in the types of technologies illustrated on Figure 1 will be potentially well-positioned to realize the substantial opportunities that are building around autonomous mobile systems. But, just how large in scale are those opportunities?

Obviously, the market size varies for each application space (for cars, over-the-road trucks, agricultural tractors, warehouse material handling, etc.), and fast-moving technology spaces can be difficult to forecast. Triangulating results from multiple recent market research reports can help put some bounds around the opportunity. Doing so (Appendix A) **places just terrestrial autonomous mobile systems at an estimated $802 billion global market by 2025-26.** Add aerial, marine, and defense autonomous systems to the market space, and the total likely climbs above $1 trillion in total market size during the mid- to late-period of the present decade.

If a region, highly skilled in the tech-stack (see Figure 2) required to enable autonomous mobile systems, were to capture just 1% of a $1 trillion global autonomous mobile systems market, that equates to a $10 billion opportunity developing over the next 5+ years. Using the U.S. manufacturing sector as a proxy to determine approximate employment that may be anticipated from a $10 billion industry output results in an estimated employment opportunity of 5,000 jobs.[4]

## The Autonomous Mobile Systems Technology Stack

Clearly, there is a very large-scale economic development opportunity for regions of the nation that have a distinctive position in the technologies and tacit know-how required to research, develop, and build complex integrated autonomous mobile systems products. It is a very specialized space, however, and as Figure 2 illustrates the "full stack " technology ecosystem needed to advance such products is quite complex.

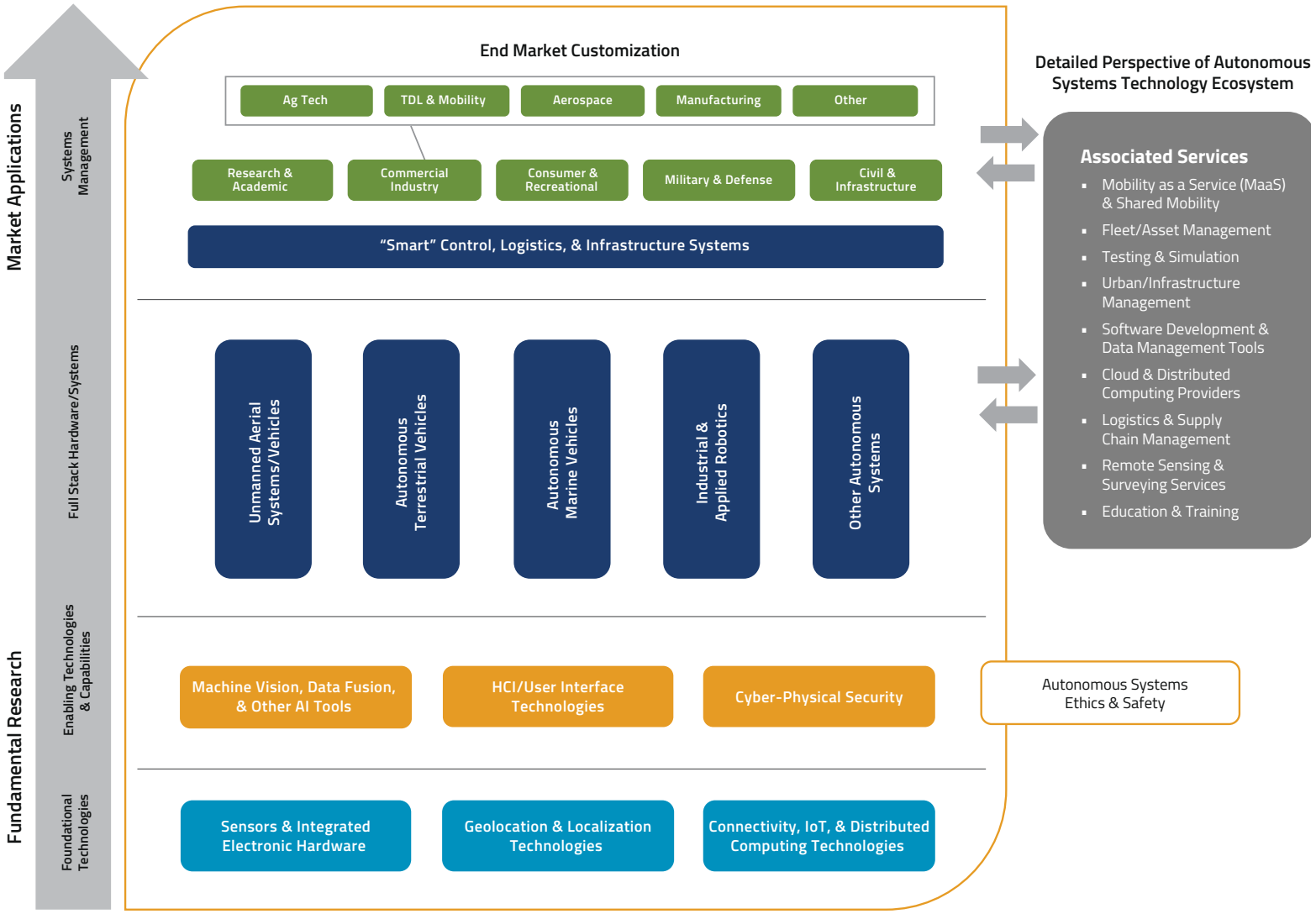
The technology "stack," a term commonly used in software engineering, represents the complete set of platforms and enabling components required to create a fully functioning system. In the context of autonomous systems, this includes the integration of all the necessary hardware and software components required for a system to perform its intended tasks without human intervention.

The technology stack builds upon layers of technologies and capabilities to enable more advanced, higher order functionality, beginning with foundational technologies and progressing to specific end market applications for full systems. The various components that form these layers include:

- **Foundational technologies**, the backbone on which further functionality and applications are built including basic connectivity, localization, and sensing functions that a system needs to perceive, interact, and communicate with the world around it.
- **Enabling technologies,** which take data and feedback generated from foundational technologies and use it to make intelligent decisions. These capabilities are highly concentrated in areas encompassing data management and artificial intelligence-related technologies, including data fusion, machine vision, and machine learning. This layer also includes capabilities required to let users interact with systems (and the data that they gather) as well as capabilities required to protect systems from bad actors and adverse events.

4 See calculation in Appendix B that the average output per worker in U.S. manufacturing = $2,000,559.33

**FIGURE 2.**
Autonomous Mobile Systems Stack




***Source:*** *TEConomy Partners*


- **Full stack systems,** which are autonomous platforms incorporating multiple sets of bundled foundational and enabling technologies in an integrated way and are designed for use in certain operating environments such as air, land, marine, or other more specific settings.
- **Systems management technologies,** which are used to manage the operation of one or more full stack autonomous systems in an intelligent way as they are assigned specific tasks to perform.
- **End market application**, where full stack systems and management functionality have been integrated into a product or service solution that is designed with a specific market application and end user in mind. Examples would include automated aerial drones for use in crop surveillance for agricultural markets, or autonomous mobile robotic platforms that perform material moving tasks within a healthcare setting.

The autonomy technology stack is highly integrated, yet also highly modular, meaning various layers can use existing third-party solutions to address any gaps in functionality. There are a variety of associated products and services that exist to provide capabilities, ranging from plug and play hardware components to industry standard software architectures. Additionally, encompassing the entire technology stack are policy and regulatory constructs that enable safe and ethical operation of autonomous systems.

## The Pittsburgh Region Has Momentum in Autonomous Systems

This is very much in evidence in terms of global multinationals investing in, or partnering with, Pittsburgh-based autonomous mobile systems operations, including for example:

- Caterpillar
- Delphi
- Ford
- General Motors
- Hyundai
- PACCAR
- Robert Bosch
- Siemens
- Toyota
- Uber
- Volkswagen
- Volvo

The sector is not only attracting investment by large multi-nationals, but also proving to be an active start-up space, with emerging new home-grown ventures. The developing supply chain contains a wide base of companies engaged in R&D and production of sensors, mapping systems, algorithm development, connectivity solutions, cybersecurity technologies, and software and systems development tools.

As a fast-growing technology sector, autonomous mobile systems shares characteristics with other digital tech sectors in terms of being favorable to new entrepreneurial business entrants, the attraction of VC and other growth capital, and high-value wealth creating liquidity events. In other words, it has many of the defining characteristics looked-for in a technology-based economic development and advanced industry sector.

To bring autonomous mobile systems solutions to market, it is not sufficient to build capacity in any one component of the technology stack. Rather, the goal of full deployment of autonomous end market solutions requires capabilities (or the ability to reliably source those capabilities) across the entire technology stack, as well as the means of linking the capabilities in each layer of the stack so that a system can perform as a fully integrated platform rather than a partial solution that requires further commercialization by others.

## An Unprecedented Opportunity

Today, as this report will show, the Pittsburgh region finds itself in a favorable position with robust R&D and innovation capabilities demonstrated across the autonomous systems stack. Pittsburgh has organically built a distinctive position in the autonomy sector, tying together two quite long-standing Pittsburgh area R&D core competencies in robotics and in computer science (especially, but not exclusively, in machine learning and artificial intelligence). Born of consistent academic leadership at Carnegie Mellon University in both robotics and computer science, and with a track record of early and sustained innovation across several robotics businesses, Pittsburgh stands in an advantageous position to realize economic growth through the autonomous mobile systems sector.

This is not to say that Pittsburgh is alone in having a distinctive opportunity to advance its economy through building an autonomous mobile systems industry. The usual technology suspects of Silicon Valley and Boston loom large here for example, but Pittsburgh is, in many respects, on a competitive footing with these locations in terms of its opportunity position, its specialized sector assets, and momentum.

# About This Study

The implications for potential economic growth around a rapidly scaling multi-billion dollar autonomous mobile systems industry, in conjunction with the apparent base of expertise and assets relevant to these technologies in Pittsburgh, have been recognized by multiple key regional stakeholders. While those engaged in advanced economic development for the Pittsburgh region have observed the organic growth of the autonomy sector, it was felt that the opportunity presenting itself to the region and the Commonwealth of Pennsylvania today is of such a scale and importance that there needs to be a formal examination of the opportunity, an evaluation made of assets to leverage and any gaps needing to be addressed in the ecosystem, and a strategy and action plan developed to guide realization of the full economic opportunity.

RIDC and the study stakeholders requested services from the technology-based economic development specialists at TEConomy Partners, LLC. (TEConomy) to:

- Define the autonomous mobile systems sector and the ecosystem that supports its development (forming a baseline understanding of the structure of the emerging industry and its constituent components);
- Assess regional R&D core competencies relevant to the sector;
- Evaluate the Pittsburgh region's current business position in the sector and associated sub-sectors;
- Develop an overview of the strengths, weaknesses, opportunities, and threats for the sector in the region;
- Understand the current and future workforce implications of sector growth in terms of key positions, required skills, and potential capacity shortfalls;
- Evaluate the Pittsburgh region's position versus other emerging autonomous mobile systems development hubs in the U.S.;
- Identify opportunities, including strategies and actions, for expanding the sector's presence in the Pittsburgh region to spur further economic development in the region; and,
- Provide an Input/Output analysis of the current economic impact of the sector in the Pittsburgh region, and provide projections for potential expanded impacts after strategic plan implementation.

# In Summary

The economic competitiveness of our nation, and individual states and regions, is strongly rooted in the capacity to advance innovation-based industries. These industries are largely rooted in STEM skills and leverage the robust investment of the U.S. in advanced research and development. One of the technology domains and emerging industries that appears well-positioned for large-scale growth is based in the convergence of advanced robotics and computer science technologies that are enabling the emergence of fully autonomous systems. A very large opportunity exists for development of autonomous systems that are mobile – able to transport people and freight or perform specific mobile tasks. This opportunity space is fast-developing and is anticipated to represent in excess of a $1 trillion global market by 2025. Requiring STEM education and skills to advance, it will also be a sector that continues to generate high wage jobs. As the sector advances, from a predominantly R&D focus into the production, sales, and service of autonomous system products and solutions, a diverse range of employment opportunities will be generated for personnel across a broad skills and education spectrum.

The RIDC and other Pittsburgh economic development stakeholders have observed the growth of a significant autonomous systems R&D sector in the region, and an expanding base of industry focused on autonomous mobile systems products, applications, and components. This study provides a formal examination of the opportunity for the Pittsburgh region to realize economic growth and generate significant new employment opportunities by further building upon its apparent assets in the autonomy technology stack. The next chapter of this report focuses on these assets.

# II. REACHING CRITICAL MASS:
## THE PROFILE OF PITTSBURGH'S AUTONOMY INDUSTRY TODAY

**The Pittsburgh region has a distinctive position as a national leader in R&D and associated innovation across the full stack of technologies that converge to create autonomous mobile systems. Built upon a deep base of long-standing specialized expertise at Carnegie Mellon University combined with early pioneering work by regional robotics entrepreneurs, Pittsburgh has organically built a robust and expanding commercial presence in autonomy that is pulling in capital investments from leading multinationals. From fundamental research to the manufacturing of already-on-the-market systems, Pittsburgh has carved-out a distinctive presence in a sector that is poised for transformational growth.**

The Pittsburgh region has a long history of research leadership in software and robotics that, driven by its core academic research institutions, has evolved into a significant base of activity at the cutting edge of modern technology applications in areas like artificial intelligence (AI), machine perception, high performance computing, and autonomous systems. Today, industry leaders, investors, and skilled talent agree that Pittsburgh represents one of the distinct hubs for autonomous systems activity in the country. Moreover, there is evidence that the regional ecosystem has reached an inflection point in developing a focus on mobile autonomous systems such that it has begun to drive an industry cluster of emerging and established companies that can serve as an economic development engine beyond supporting continued excellence in R&D. However, Pittsburgh's industry cluster is still nascent and will continue to be shaped by the broader market headwinds that are influencing the path industry will take to deploying autonomous solutions at scale.

## An Organic Innovation Ecosystem Fueled by Research Excellence

At the heart of the Pittsburgh region's innovation ecosystem is a base of academic research institutions that support translational research activity and produce highly skilled talent. For autonomy industry applications in particular, the region's research and innovation core competencies reflect a history of excellence in the underlying technologies that now support full stack autonomy development and testing within academe and industry.

As a means of assessing the breadth and depth of recent research strengths that are aligned with the autonomy sector, TEConomy profiled the region's footprint in peer-reviewed publications from 2016 to early 2021 in research areas with potential relevance to the autonomous systems technology stack. Key scientific disciplines included in the context of the analysis spanned engineering, computer science, mathematics and statistics, and some portions of applied materials sciences and physics while other disciplines such as medicine, arts, and humanities were excluded (see Appendix E for further detail). Using machine learning algorithms to analyze the descriptive text content from over 14,600 peer-reviewed publication records in these disciplines produced by regional institutions during the time period, the analysis showed that over 71% of

the total descriptive content of those publications had some relevance or potential supporting role for advancing autonomous systems technologies. The topics identified through this analysis, highlighted in Figure 3, span "basic science" autonomy-enabling capabilities in artificial intelligence and data fusion to applied research in machine vision and edge computing. Most notably, almost 19% of the analyzed research publications content deals directly with autonomy or the AI and machine learning capabilities that directly support its deployment (for further information on core competencies identified through this analysis, see Appendix E). This focus on applied sciences and technologies that make up critical pieces of the autonomous mobile systems stack highlights the deep strengths the Pittsburgh region is leveraging as it grows its industry presence in this space.

### Research as an Ongoing Innovation Driver

Technology industries are characterized by a fast pace of change – with product life cycles being relatively short, and ongoing product evolution and improvement being critical to business success. This is, and will continue to be, a defining characteristics of the autonomous mobile systems sector.

Because of this, there is a strong imperative to sustain investment in research – both fundamental and applied research – that powers the innovation process. Research performers of all types – academic, government lab, and industry – serve important roles in the U.S. R&D ecosystem and sustaining robust levels of R&D funding to these research actors is critical to economic development success and U.S. international competitiveness.

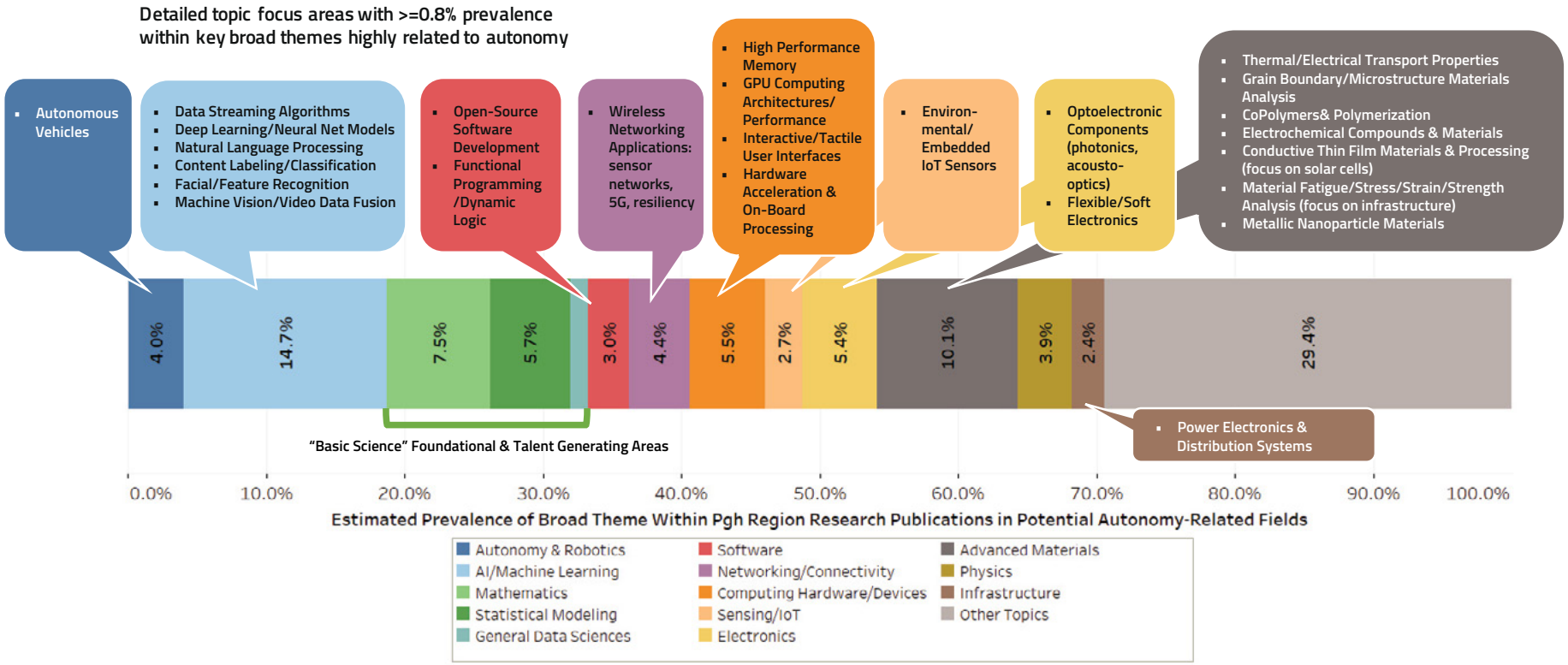
Additionally, a review of recent grant awards to Pittsburgh region research institutions from 2015 through early 2021 further highlights the significant level of relevant research activity occurring in the region. As shown in Table 1, autonomy-related grant activity funded by the National Science Foundation (NSF), Department of Defense (DoD), Department of Energy (DoE), and the National Aeronautics and Space Administration (NASA) totaled almost $163 million, representing more than 12% of all grant funding activity to Pittsburgh institutions from these sources over this time period. These totals do not include the significant additional contract research work performed directly for government agencies by Pittsburgh institutions.

**TABLE 1.**
**Autonomy-Related Grant Award Funding to Pittsburgh Institutions, 2015-early 2021**

| Autonomy-Related Grant Focus Area | NSF Total Grant Funding, 2015-2021 ($M) | DOD Total Grant Funding, 2015-2021 ($M) | DOE Total Grant Funding, 2015-2021 ($M) | NASA Total Grant Funding, 2015-2021 ($M) |
|---|---|---|---|---|
| AI & Machine Learning | 9.1 | 39.1 | | 0.5 |
| High Performance Computing | 1.9 | 7.3 | | |
| Cyber/Cyber-Physical Security | 3.5 | 15.3 | | |
| Hardware & Components | 3.2 | | | |
| Sensing & IoT | 9.0 | 2.9 | 1.5 | |
| Robotics & Full Stack Systems | 11.3 | 50.7 | 5.1 | 2.5 |
| **Total** | **38.0** | **115.3** | **6.6** | **3.0** |

***Source:*** *TEConomy analysis of federal grant award data via NSF and USAspending.gov*

**FIGURE 3.**
## Identification of Pittsburgh Institutional Research Competencies Using Latent Topic Modeling and Research Publications Data




***Source:*** *TEConomy analysis of Clarivate Web of Science publications data*


### Carnegie Mellon University's National Robotics Engineering Center

NREC represents a signature applied research and commercialization institute that assists government and industry clients in rapid prototyping and functional testing of robotics systems.

NREC has a long history of successful innovation in autonomous systems, with highlights that include:

- $400+ million in total funding
- 850+ individual inventions
- 330+ successful projects
- 45 licenses
- 130+ customers.

Collectively, the deep level of regional research activity in areas highly aligned with numerous elements of the autonomous systems technology stack represents a signature strength for Pittsburgh that positions it amongst the top ecosystems in the country in generating the technology and talent "push" that drives ideation and subsequent opportunities to commercialize innovative technologies.

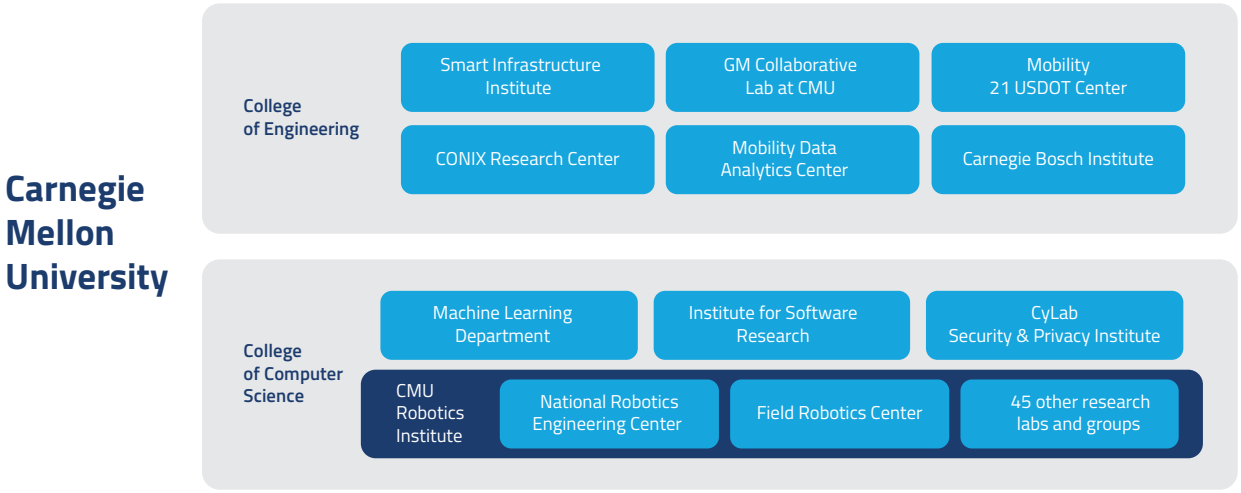
Anchoring these regional strengths as a national leader in areas of innovative research and applied technologies that directly supply and attract the autonomous systems industry is Carnegie Mellon University (CMU). The extent to which the university represents a signature supporting asset is shown in its world-leading position in CS Rankings data that indexes major computer science publications and ranks institutions based on their activity at the most prestigious computer science conferences.[5] Amongst all institutions globally, CMU is ranked first over the 2015 to 2021 time period in AI-related publishing with 73 publishing authors (by contrast, the next closest U.S. institution in the rankings has 49 publishing authors). In the area of robotics CMU is ranked third globally over the same time period with the highest number of publishing authors (29, the leading institution has 23 publishing authors). This level of research excellence is confirmed by the university's high specializations in computer science and robotics discipline areas indexed across the broader Web of Science set of peer-reviewed publications over the same time period.[6]

5 CSRankings documentation notes that the data is intended to rank academic departments by their presence at the most prestigious computer science publication venues as a means of assessing leading research institutions. Research areas included in the rankings data are based on the Association for Computing Machinery (ACM) Special Interest Groups which represent major areas of computer science and are included based on a criteria of having at least 50 R1 institutions with publications in top conferences in that research area over the last 10 years. Note that CSRankings leverages the DBLP computer science bibliography which provides information on major computer science journals and proceedings. DBLP indexes over 4.4 million publications but does not currently index general science journals such as Science, Nature, and PNAS.

6 See Appendix E

CMU's leading position has acted as an industry attraction asset for the region over the past decade, drawing in numerous corporate R&D operations that are seeking to mine the talent and research occurring within its ecosystem. Similarly, CMU's National Robotics Engineering Center (NREC) and other key labs and institutes within the university have acted as commercialization engines for CMU technologies, generating startups and industry thought leaders which have remained rooted in the area to anchor the growing autonomous systems industry cluster. Figure 4 highlights the depth to which the institution is organized to specifically support disciplines in applied robotics and artificial intelligence that enable autonomous systems innovation and translational research.

**FIGURE 4.**
**Primary Centers and Institutes Aligned with Autonomous Systems R&D at Carnegie Mellon University**




## Innovative, Homegrown Companies Driving Signature Investments

The region's excellence in fundamental and applied research has in turn driven organic growth of a cohort of thought leaders focused on the autonomy industry. These have expanded the cluster over the last decade to its current critical mass. Often beginning as spinouts or founded by alumni affiliated with regional research institutions such as CMU and the University of Pittsburgh, several of these companies have grown to attract significant venture and direct corporate investments that have raised the region's profile in autonomous systems over the past five years.

Many of Pittsburgh's autonomous systems companies have been able to successfully leverage venture capital investment to continue to scale towards mass deployment of solutions, but they have typically had to rely on sources of funding from outside of the region (with the Pittsburgh region lacking dedicated funds focused on the autonomous sector). Traditional venture capital investment (investment classes that do not include mergers, acquisitions, direct corporate investment, and other financing outside of the traditional risk capital stack) has helped spur the growth of a wide range of local companies that are focused on a diverse set of markets, ranging from industrial robotics to enabling software (see Table 2).

**TABLE 2.**

## Leading Autonomy-Related Companies in Pittsburgh Region Receiving Traditional Venture Capital Investment, 2015-present (Does not include deals classified as M&A and corporate investments)

| Company[7] | Company Focus | Total VC Investment Raised to Date ($M) |
|---|---|---|
| Seegrid | Developer of autonomous industrial vehicles, autonomous mobile robots, and material handling automation solutions | 152.48 |
| Aethon | Developer of autonomous mobile delivery robots | 100.0 |
| RedZone Robotics | Provider of robots and software tools for wastewater asset management services | 58.6 |
| Gecko Robotics | Developer of robots intended to automate infrastructure inspections | 47.1 |
| Fifth Season | Developer of robotics-driven indoor vertical farming system | 37.8 |
| Locomation | Developer of human-guided autonomous trucking convoy technology | 28.5 |
| IAM Robotics | Manufacturer of autonomous mobile manipulation and picking robots | 20.7 |
| Edge Case Research | Developer of autonomous vehicle safety and software testing systems | 15.0 |
| Maven Machines | Developer of fleet management and telematics platform with applications in autonomy | 13.4 |
| RoadBotics | Developer of computer vision technology designed to inspect roads and infrastructure | 12.4 |
| Bito Robotics | Developer of mobile robots for smart manufacturing and logistics operations | 9.1 |
| Near Earth Autonomy | Developer of low-flying aircraft sensors for autonomous aerial systems | 8.0 |
| Kaarta | Developer of 3D modeling software and hardware with applications in autonomy | 6.8 |

***Source:*** *TEConomy analysis of Pitchbook VC data*

### Pittsburgh's Autonomous Vehicle Companies Driving Major Investment in the Region

- In June of 2020, local company Argo AI finalized a joint investment with Ford and Volkswagen totaling $2.6B
- In December of 2020, Aurora acquired Uber's self-driving ATG unit in an equity deal valued at $4B with Aurora's H2 now located in Pittsburgh. The company recently announced it will be going public with an IPO.
- First announced in March 2020, Motional was formed as joint partnership between Aptiv and Hyundai with major employment presence in Pittsburgh as a result of acquiring a Carnegie Mellon spinout.

The venture capital performance of the sector is notable, however the clearest indicator that the region's autonomous systems sector has reached critical mass is demonstrated by the success that the autonomous vehicles sector has had in attracting signature corporate investment from major automotive manufacturers. Beginning in 2015 with the opening of Uber Advanced Technologies Group (ATG) in Pittsburgh, the region's autonomous vehicles companies have continued to drive employment growth,

[7] Aurora also received ATG's Pittsburgh VC investment in the time period, however Pitchbook allocates the investment to Aurora's California location. Aurora closed 6 total VC deals from 2015 to present totaling $1,217.54 million and a significant proportion of this investment will have benefitted Pittsburgh-based Aurora operations.

investment, and national attention towards the local industry sector. These efforts culminated in 2020 with multi-billion dollar investments across several different Pittsburgh autonomous vehicles companies representing a significant milestone for the industry cluster's growth. **Major automotive manufacturers made signature investments in Argo AI ($2.6 billion from Ford and Volkswagen), helped form Motional as a joint venture ($4 billion joint venture between Aptiv and Hyundai with significant operations in Pittsburgh), and AV company Aurora acquired Uber ATG's operations (acquisition deal valued at $4 billion, Aurora is partnered with Volvo and Honda).** These investments have helped to firmly establish the region's reputation as a hub for the autonomous systems cluster and drive further attraction of strategic growth partners and skilled talent to the local ecosystem.

## Advancing a Diversified Set of Technologies and Markets

As Pittsburgh's autonomous systems industry has matured it has begun to take on a broader economic development identity that can serve as the foundation for a successful industry cluster that incorporates further innovation, entrepreneurship, successful companies, and industry supply chains. **There are now more than 70 companies directly serving the autonomous systems industry and its supporting technology stack located in the Pittsburgh region that span a wide array of technologies and target end markets.** Dozens of these companies have begun to spatially cluster around shared infrastructure and proximity to one another along the Allegheny River stretching from the Strip District to Lawrenceville, a location dubbed "Robotics Row" by local and national media[8] that has taken on an innovation district-like role for emerging robotics, AI, and autonomy companies. Another developing locational hub for the sector is in Hazelwood Green, which also has good land availability for expansion.

Even though the region's growth in autonomous vehicles has received most of the national attention, Pittsburgh hosts a much broader set of companies focused on nearly every end market application for autonomous systems. As shown in Figures 5 and 6, not only does the current set of companies demonstrate a focus on deployment into multiple markets (which have further specialized applications within specific industries), but within those markets they are integrating and deploying multiple elements of the technology stack ranging from electronic components and software to full systems. Companies thriving in this ecosystem outside of the autonomous vehicles market include scaling local businesses such as Seegrid who are capturing significant shares of the sizable end markets for industrial autonomous systems and logistics. Additional emerging and mid-size companies span diverse market applications including autonomous agricultural robotics (Fifth Season, an AI and robotics-driven indoor farming company), autonomous bridge construction (Advanced Construction Robotics, which deploys large scale robots to automate rebar installation), and intelligent mobile manipulation solutions (RE2 robotics, whose platform serves multiple end markets in automating skilled manipulation tasks to improve safety and efficiency) to name only a few examples. Figure 6 provides an illustration of this company and application diversity within the Pittsburgh region, showing application areas and some of the companies operating in the Pittsburgh region (both local-grown companies and multi-location/multinational companies).

8 https://news.crunchbase.com/news/pittsburgh-an-emerging-hotbed-of-robotics-ai-companies/ and https://archive.triblive.com/local/pittsburgh-allegheny/tech-firms-keep-expanding-robotics-row-pittsburghs-mini-silicon-valley/

**FIGURE 5.**

## Estimated Current Employment at Autonomous Systems Companies in Pittsburgh, by Technologies Deployed and Markets Served*

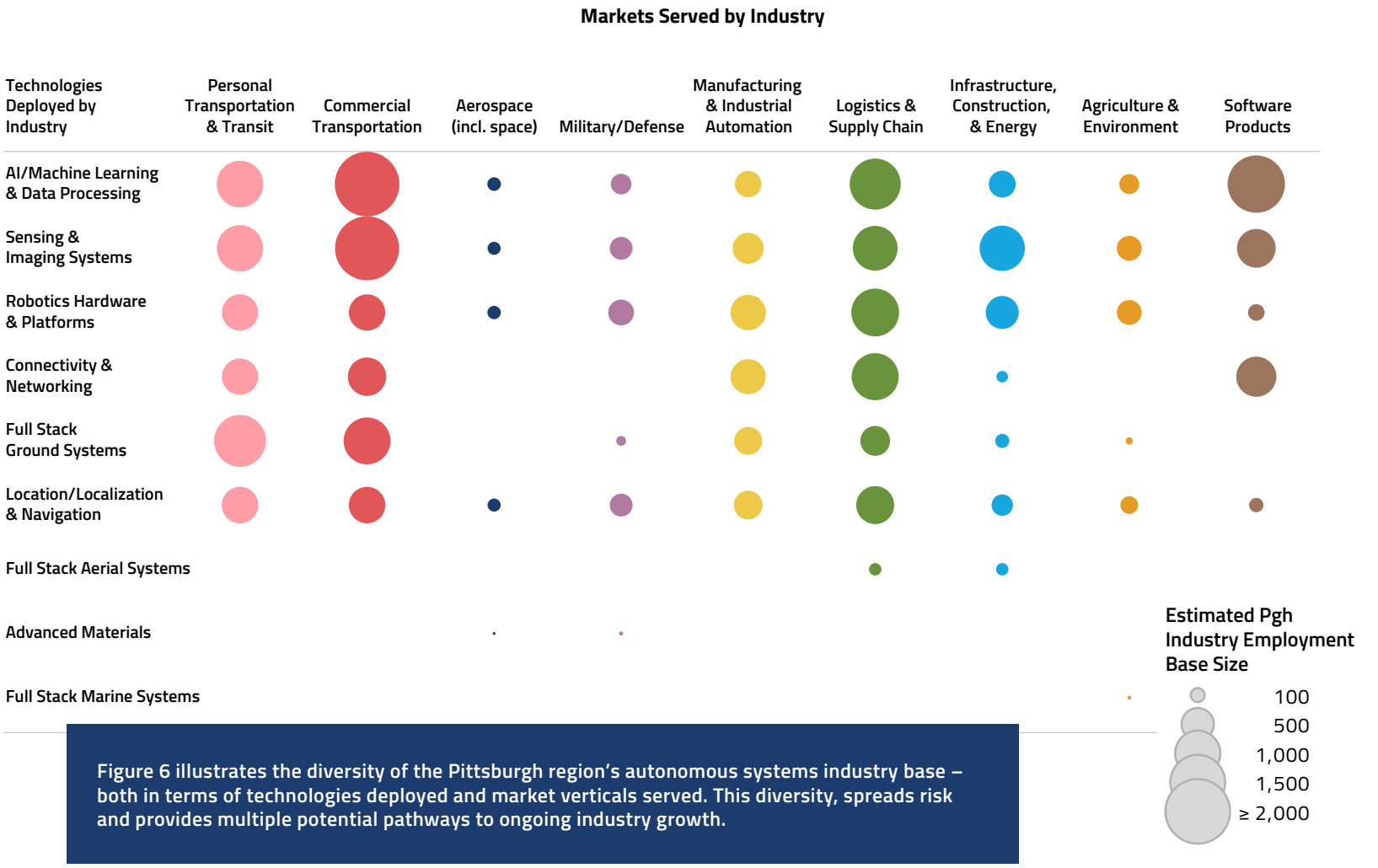
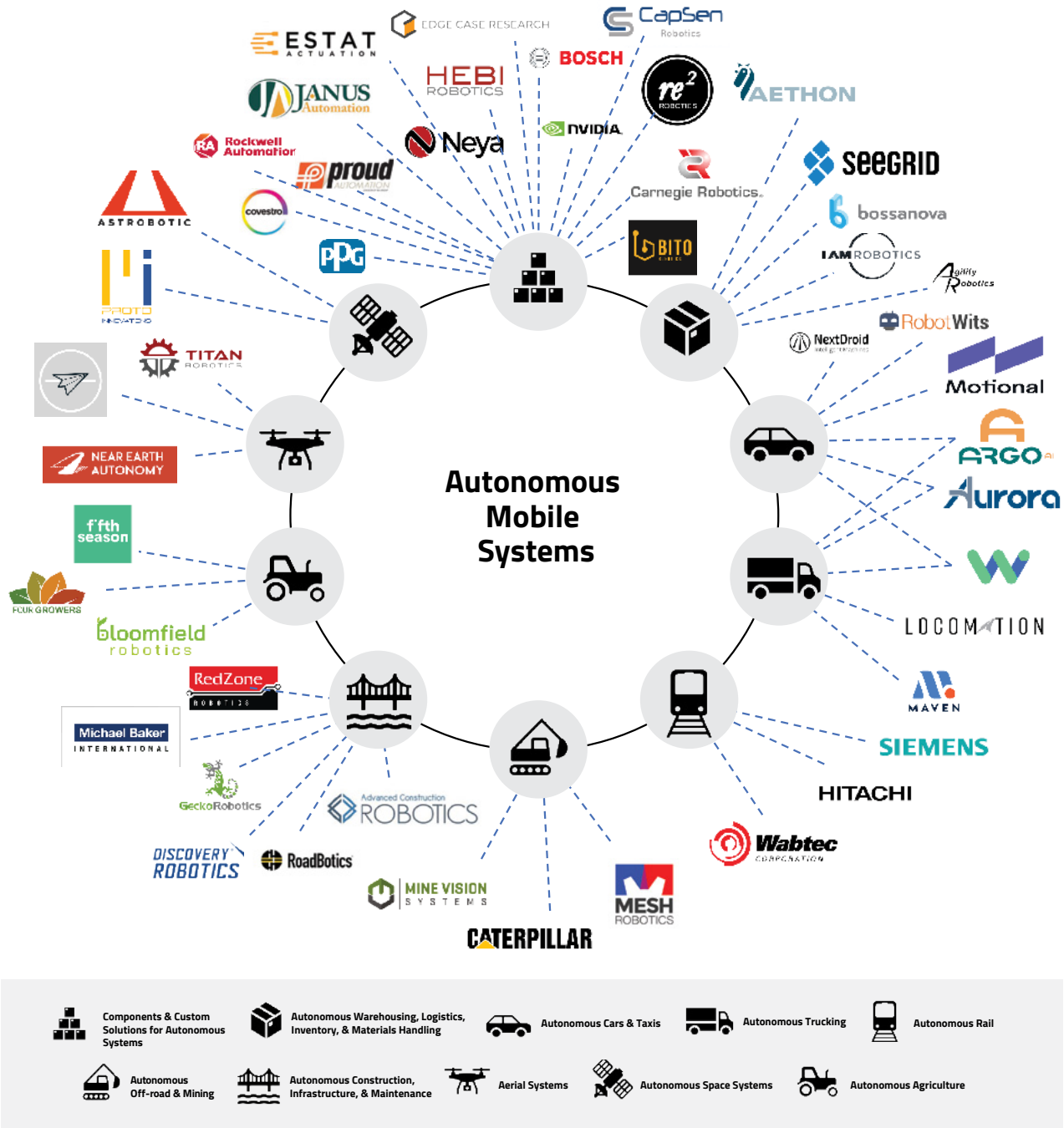



Figure 6 illustrates the diversity of the Pittsburgh region's autonomous systems industry base – both in terms of technologies deployed and market verticals served. This diversity, spreads risk and provides multiple potential pathways to ongoing industry growth.

***Note:** companies may deploy multiple technologies and serve multiple end markets as a part of their business activity*

***Source:** TEConomy analysis of Pitchbook VC, SBIR, USPTO, company LinkedIn profile, and other data*

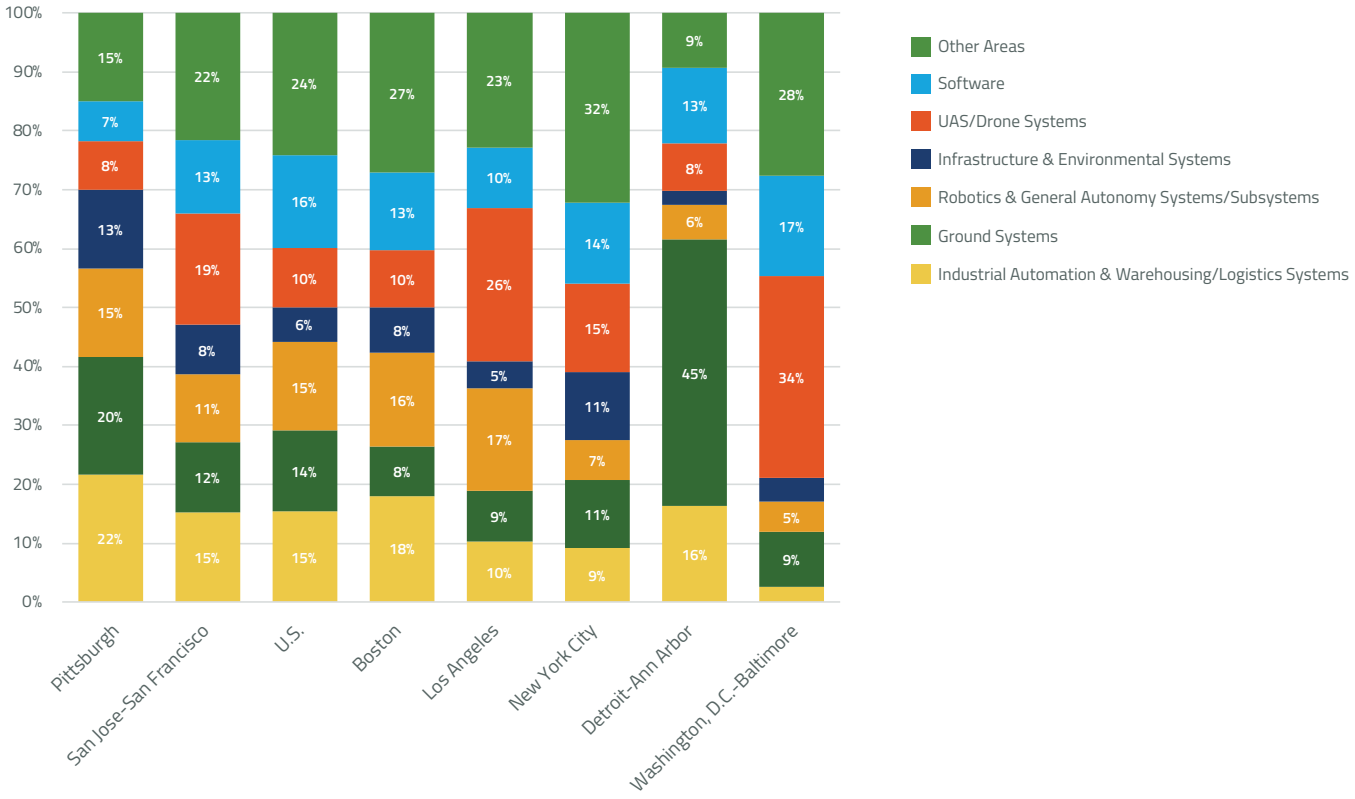
**FIGURE 6.**
Examples of the Diverse Base of Companies Operating in Autonomous Mobile Systems Verticals Within the Pittsburgh Ecosystem




Relative to other locations with significant business establishments focused on the autonomous systems industry, **this diversity stands out as a key competitive strength** that can help the region remain agile to shifts in broader markets as adoption of autonomy solutions grows. As seen in Figure 7, Pittsburgh's mix of businesses serving applied markets in

robotics systems and subsystems, industrial, warehousing, and logistics autonomy, ground systems, and infrastructure and environmental applications is the most diversified amongst other major regions in the U.S. that are highly active in this industry. **As the industry continues to grow, leveraging this diversity towards new opportunities will be critical to maintaining the growth trajectory the industry has enjoyed over the last five years.**

## FIGURE 7.
### Estimated Percentage of Autonomous Systems Industry Establishments by Broad Market Segment Focus, Pittsburgh, U.S., and Other Major Cities[9]




***Source:*** *TEConomy analysis*

9 This graphic is not proportionate to the size of the autonomous mobile systems sector in each of the listed metropolitan areas in terms of either employment or business output. It is based on a raw count of business establishments only, serving to show comparative business sector mix only (not comparative scale).

# A National Autonomy Hub Positioned for Growth

Both local and external stakeholders have begun to recognize the depth of Pittsburgh's innovation enterprise as well as the breadth of its growing industry presence in autonomous mobile systems. The region's continuing legacy of deep technical expertise in the fundamental enabling technologies of autonomous systems as well as its recent growth spurred by signature investments from major corporate partners have driven broad stakeholder consensus that **the region's industry has reached critical mass and is recognized as one of a select few U.S. geographic hubs specializing in autonomous systems** alongside peer regions in the San Francisco Bay Area and Boston.

The maturation and scaling of Pittsburgh's autonomous systems industry has several important implications for the region. First, talent attraction to the region for the industry is substantially "de-risked" relative to past conditions as there is now a perception that there are multiple geographically co-located industry destinations for incoming talent to rely on for employment opportunities. Second, the region has built up enough critical mass to draw attention from a broader national and international pool of potential investors and partners focused on autonomous systems applications. Finally, the region has been able to "root" a cohort of headquarters operations and successful business leaders in the region that can serve to enhance the region as a destination for other autonomous systems companies (or their suppliers) seeking to be a part of a vibrant innovation ecosystem.

Despite the region's success in growing its industry cluster organically, most end markets for autonomous systems have not yet seen large-scale productization and deployment of systems. Market dynamics are still primarily driven by proactive investment in anticipation of future demand and adoption. This makes a line of sight to specific growth opportunities less reliant on established markets to realize success and obviously carries a degree of risk. This is typically the case with innovative disruptive technology, and the region needs to be willing to absorb/share in this risk, taking bold action to solidify its status as a national leader in autonomous systems.

The region does have a number of potential growth opportunities it can seek to leverage as it continues to scale. At the intersection of potential market drivers and Pittsburgh's regional technology and talent core competencies lie a number of strategic areas of opportunity. These areas, which leverage the region's deep expertise in applied sciences and technology demonstration, include:

- **On-Road Autonomous Vehicles**, driven both by significant industry innovation activity in autonomous cars but also by an emerging focus on autonomous trucking platforms.

- **Off-Road Autonomous Vehicles** spanning a variety of markets that require highly technical solutions including the automation of construction and mining vehicle operation to improve safety and reliability, defense and other specialty off-road vehicles that require advanced decision-making capabilities to function in challenging environments, and urban air mobility solutions that can support both cargo and passenger transport applications in the built environment.

- **Industrial and Logistics Automation Systems** that include material moving systems and autonomous mobile robots (AMRs) to improve operational safety and efficiency, intelligent mobile manipulation systems that can automate skilled, repetitive tasks to address workforce shortages, and automated observation and tracking systems to gather data that supports the digital supply chain.

- **Construction and infrastructure systems** that integrate robotic automation into legacy industries to help augment the labor force using construction robotics systems as well as provide better monitoring of physical assets using remote inspection systems.

- **Specialty robotics hardware and components** that leverage the region's world class capabilities in machine vision systems and embedded controllers and processing to supply solutions to a growing global stock of autonomous systems.

- **Autonomy support and services** that support the autonomous systems industry as it grows and enable more effective adoption and deployment of new solutions through precision localization data & services, environmental mapping and digitization, embedded sensor systems, and security and safety solutions.

Figure 8 shows both the estimated size of the end markets these opportunities are likely to serve as they scale to mass deployment as well as the time horizons over which the scaling is likely to occur. Pittsburgh's opportunities are relatively distributed across both markets and time horizons to maturity, and the region can continue to position itself for future growth by supporting a diverse portfolio of autonomy applications.

**FIGURE 8.**
**Profile of Strategic Growth Opportunity Areas for Pittsburgh's Autonomous Systems Industry**

| | **Nearer Time Horizon to Scalability** | **Longer Time Horizon to Scalability** |
|---|---|---|
| **Specialty Markets** | ▪ Mining vehicles<br>▪ Defense and other specialty off-road vehicles<br>▪ Intelligent mobile manipulation | ▪ Urban air mobility<br>▪ Specialty Robotics Hardware & Components |
| **Broader Potential Markets** | ▪ Autonomous trucking<br>▪ Material moving systems (industrial and logistics applications)<br>▪ Construction robotics<br>▪ Remote inspection systems<br>▪ Agricultural robotics | ▪ Autonomous cars<br>▪ Autonomy support and services |

Pittsburgh's broad set of opportunities make it well-positioned to realize growth, but there is still some uncertainty about which specific industry sectors will drive mass adoption as the market is still waiting for first movers to de-risk large scale pathways to deployment. If Pittsburgh can embrace strategies to drive a growing, diverse base of companies that can leverage the expertise of the regional innovation ecosystem to quickly respond to new opportunities, then the autonomous systems industry has the potential to drive decades of future economic growth for the region.

# III. AN EMERGING COMPETITIVE LANDSCAPE:
## THE NEED FOR BOLD ACTION TO SECURE PITTSBURGH'S POSITION

**Other regions have recognized the transformational economic promise of autonomous mobile systems and are organizing to build their clusters, invest in signature infrastructure, and aggressively attract business. While Pittsburgh remains a national hub for autonomy and robotics innovation today, the region does not have an unassailable position considering the strategic actions being taken by other states and regional innovation ecosystems. There is an urgent need for major investments to be made and for strategic coordination of Pittsburgh's innovation assets serving the autonomous systems sector that will ensure the region is able to accelerate its growth rather than fall behind and be overtaken. Significant economic impacts are at stake, with more than 71 companies and 6,300 jobs in the region today that support an estimated total of $3 billion in economic output.**

Growing alongside the Pittsburgh region's industry and innovation presence, a broader global market for autonomous systems anchored by other regional innovation hubs has also emerged. Within the U.S., states and regions are taking action to position themselves to be at the forefront of emerging technologies and market applications associated with the industry sector. Coupled with broad uncertainties about the exact pathway and timing to mass deployment of autonomous solutions within various end market verticals, the outlook for Pittsburgh's future within this increasingly competitive space is far from assured if the region takes a passive stance and relies solely on existing industry and innovation activities. Pittsburgh's current position as a national leader in AI, robotics, and autonomous systems R&D affords it an enviable competitive advantage that it can use to accelerate the growth of its industry base and position itself as an epicenter of future innovation activity, but only if the region is able to take proactive steps to retain its existing industry, support new cohorts of emerging companies, and attract new industry, talent, and infrastructure to the region as it competes for market share with others.

### Will History Repeat Itself?

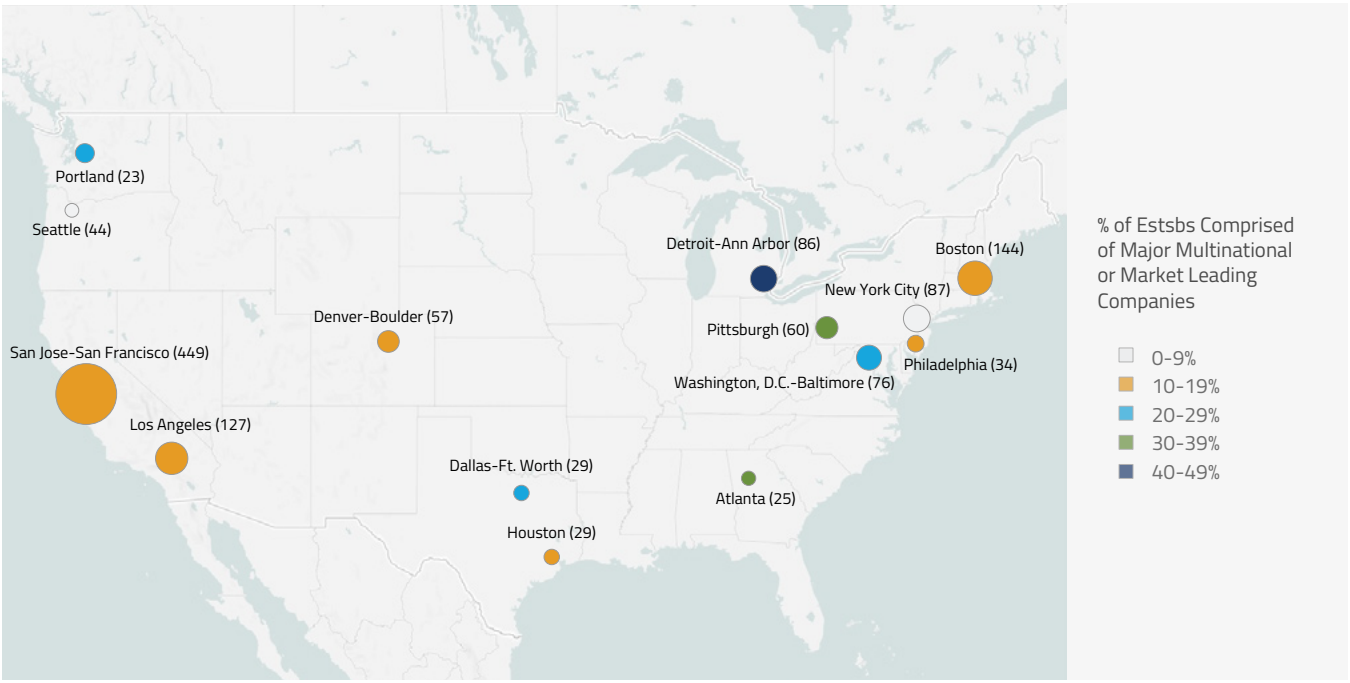
In the early days of the Internet, Pittsburgh's cyber expertise birthed some promising businesses, but not at the rate required to make the region a true leader, and the ecosystem was not fully built-out to assure success. The opportunity was not capitalized on. The dot.com boom, similarly, produced some action, but it is hard to point to major residual economic drivers in the Pittsburgh region from that. Even in a space where Pittsburgh excels in R&D, biomedical sciences, the success rate in terms of building an industry around that R&D excellence has been moderate at best. The fact is that the region, and the state within which the region sits, has not been able to fully leverage the opportunities that have been presented. That is not to say that initiatives have not been formed, organizations stood up, and funding directed at opportunities – rather it has been the case that these have not been sufficient to build a robust technology-based economic development leadership position in the industries that the programs sought to nurture.

# Benchmarking the Emerging Industry Footprint

As an emerging, R&D intensive industry that does not yet have widely productized goods and services or large volume consumer bases, the broader landscape of the autonomous systems industry is often difficult to fully characterize. To better understand the current state of the autonomous systems industry and Pittsburgh's place within it, TEConomy leveraged a portfolio of data sources[10] to build out a national database of mobile autonomous systems companies and their key supplier and supporting service companies. The assembled data is limited to establishment sites whose primary business focus is mobile autonomous systems and subsystems (including hardware and software), with the resulting landscape of the U.S. industry cluster distribution providing a snapshot of the current competitive landscape where other hubs of critical mass are emerging.

The profile of the broader U.S. industry footprint identified 1,848 business establishments primarily engaged in producing goods and services for the mobile autonomous systems industry. As Figure 9 below shows, the Pittsburgh region's autonomous systems industry is hardly alone amongst a growing base of geographic regions who have their own expanding industry clusters. This highlights the trend towards an increasingly competitive market landscape, with other regions seeking to build or expand their own industry bases to take advantage of new opportunities in autonomy deployment applications.

**FIGURE 9.**
**Distribution of U.S. Autonomous Systems Industry Establishments, Combined Statistical Areas with 20 or more Establishments**



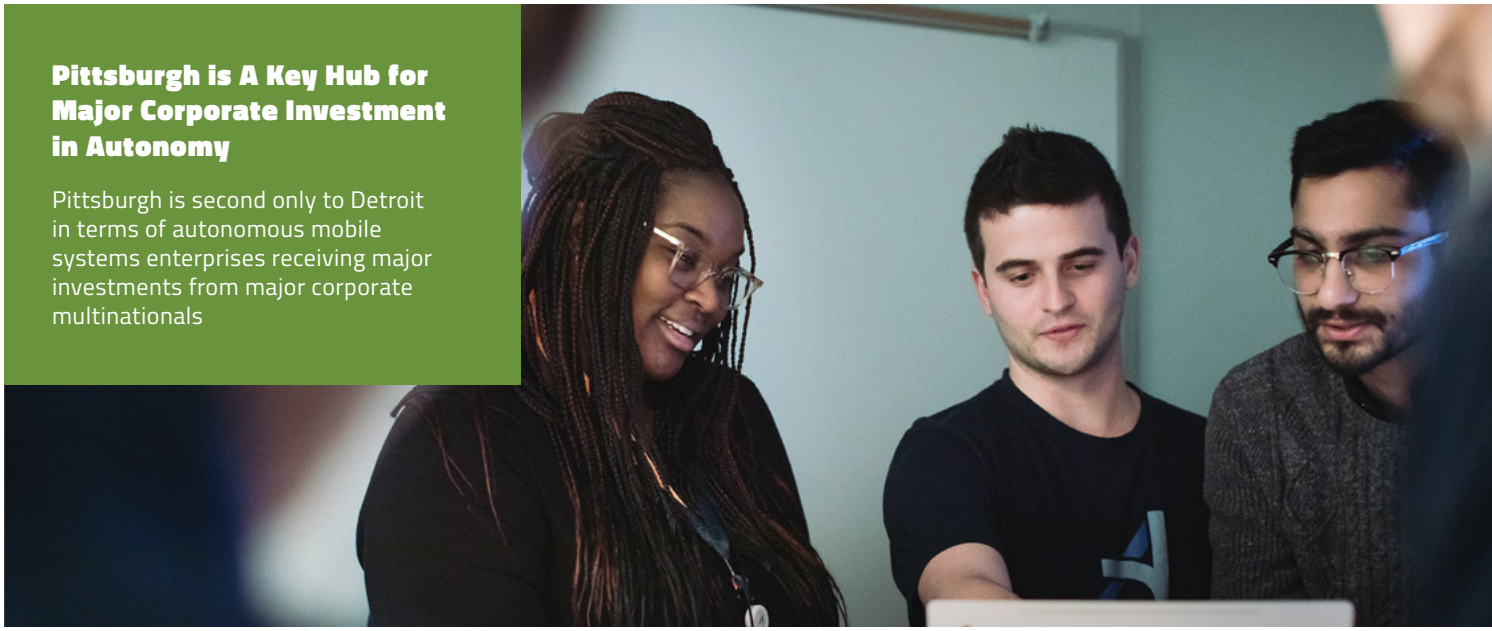

***Source:*** *TEConomy analysis of BCC and IBISWorld Market Research, Pitchbook VC data, SBIR data, and AUVSI unmanned systems database*

**The Pittsburgh region ranks 7th nationally in the dataset in terms of its volume of business establishments (60 total establishments, 3.2% of national total)** behind several other regions such as the San Jose-San Francisco-Oakland region (449 establishments, 24.3% of national total) and the Boston-Worchester-Providence region (144 establishments, 7.8% of the national total). Below these two national leaders, there is a cohort of regions that has a similar industry establishment base size to Pittsburgh including New York-Newark, Detroit-Warren-Ann Arbor, Washington-Baltimore-Arlington, and Denver-Aurora.

10 Market research, Pitchbook, AUVSI database, news articles

### Pittsburgh is A Key Hub for Major Corporate Investment in Autonomy

Pittsburgh is second only to Detroit in terms of autonomous mobile systems enterprises receiving major investments from major corporate multinationals



A raw count of industry establishments only tells one part of the story, however. Perhaps more importantly, the analysis of autonomy industry activity shows that larger companies demonstrating market leadership, as well as major multinationals that are making investments in autonomous systems technology, tend to make up a large and notable share of the industry establishments in the Pittsburgh region. **These companies make up 38.3% of Pittsburgh's industry establishments, a higher proportion than any other region in the U.S. outside of the Detroit-Warren-Ann Arbor region which had 48.8% of its establishments in this category.** The concentration of major autonomous systems companies within Pittsburgh's industry base is a distinctive characteristic.

## States are Increasingly Recognizing the Opportunity

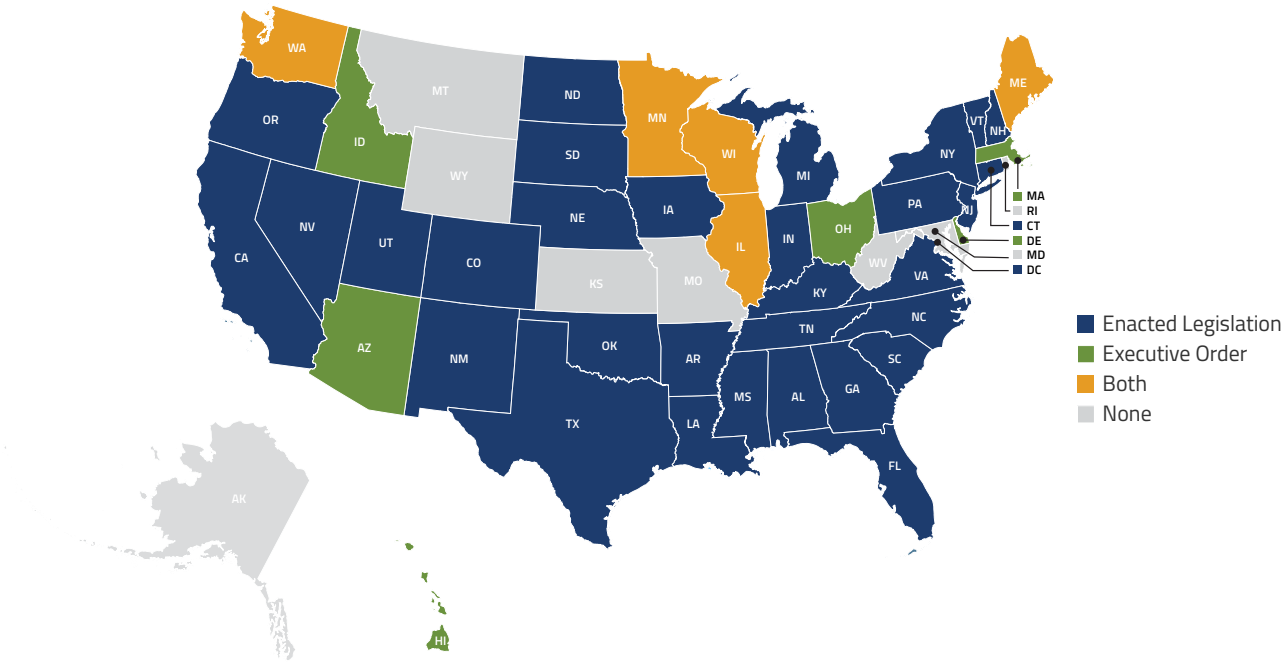
As the autonomous systems industry continues to expand nationally, states are also increasingly undertaking economic development and public policy actions to position themselves to capture market share. Much of this activity is focused on policies that enable testing of autonomous systems within states as well as sources of funding for demonstration and infrastructure projects that incorporate autonomous solutions as a part of their efforts.

Although the legislative landscape around autonomous vehicles remains a patchwork of state-level regulations at present, states have begun to recognize that consistency and transparency in regulatory and operating environments are key determinants of industry attraction. States advancing forward-thinking regulatory environments (see text box on pages 25 for recommendations to advance Pennsylvania in this regard) will have competitive advantages as companies move to expand testing as they scale towards mass market deployment, which has driven a flurry of recent activity as legislators seek to create more business-friendly environments. This is most evident in state policymaking related to autonomous vehicles testing which has greatly expanded since 2013:

> *"According to the National Conference of State Legislatures (NCSL), between 2013 and 2020, 31 states and the District of Columbia enacted legislation related to autonomous vehicles, governors in 11 states issued executive orders, and 5 states both issued an executive order and enacted legislation."*[11]

11 Congressional Research Service, Issues in Autonomous Vehicle Testing and Deployment, April 2021

**FIGURE 10.**
## State Enacted Legislation and Executive Orders Related to Autonomous Vehicles, 2013-2020



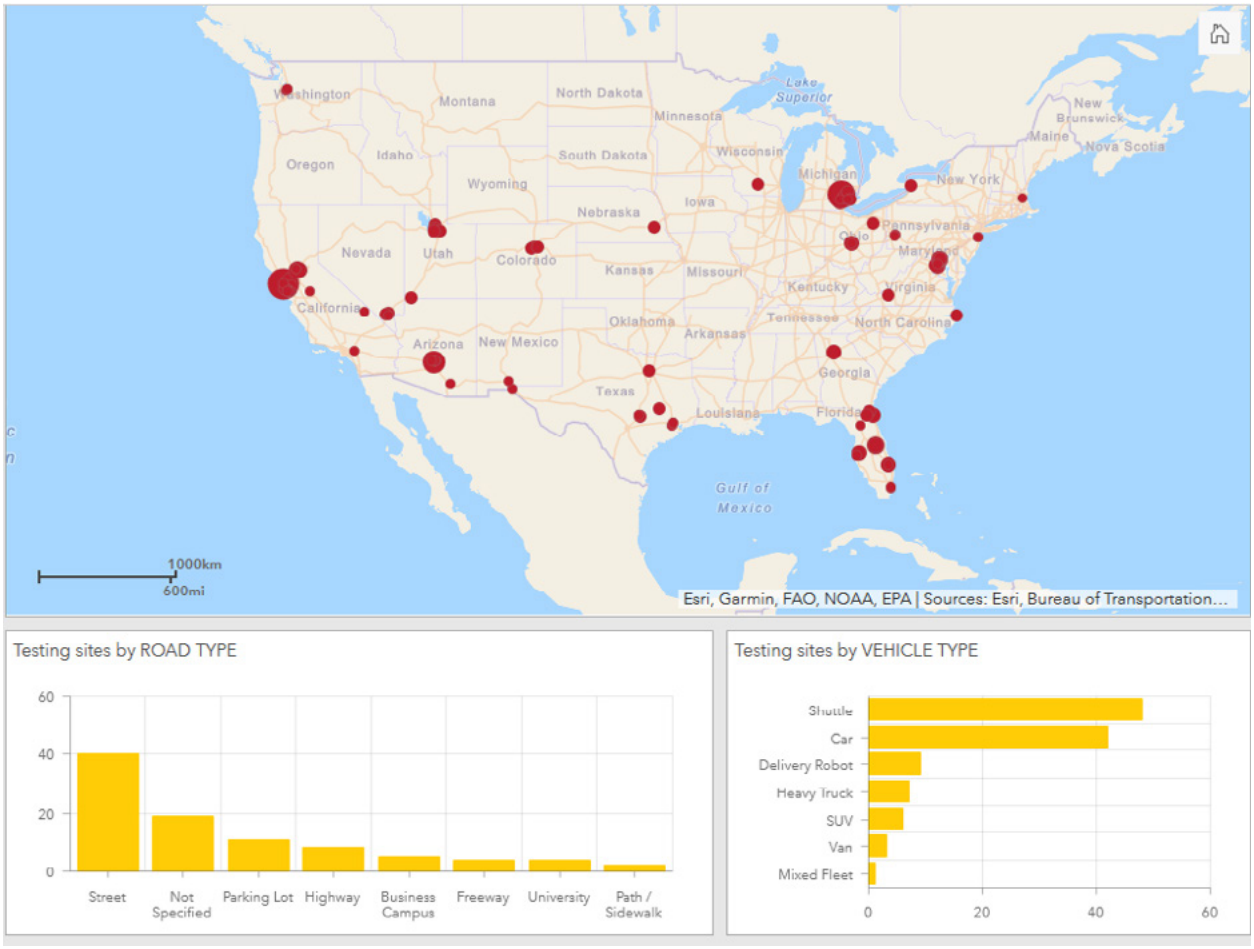

***Source:*** *Congressional Research Service, Issues in Autonomous Vehicle Testing and Deployment, April 2021.*

Additionally, as the Federal Aviation Administration (FAA) has expanded its drone and unmanned aerial systems (UAS) test site programs to advance R&D applications since 2012, states have also responded by enacting legislation to guide the emerging opportunity. NCSL again notes that "*since 2013, at least 44 states have enacted laws addressing drones and an additional three states have adopted resolutions.*"[12] These actions typically address the use of UAS platforms by emergency responders, appropriate operating environments, and established funding for certifications, development programs, and public-private partnerships.

The results of state action are starting to be realized through the attraction of autonomous systems testing efforts to regions across the country as companies continue to advance their platforms. In the autonomous vehicles sector alone, the distribution of autonomous vehicle testing sites reported by industry (seen in Figure 11) spans not only the major research and industry hubs in this sector, but also many additional states that have the appropriate environmental and regulatory conditions that are attractive to companies. In contrast to the southwestern Pennsylvania region, other areas of the country in Nevada, Arizona, Texas, and Florida have more testing sites that incorporate higher numbers of autonomous vehicle platforms. The spread of reported testing and demonstration operations across the country over only the last two years highlights the urgency behind many state actions to create a policy environment seen as receptive to industry deployment of autonomous systems in hopes that companies will base site location decisions on proximity to testing infrastructure.

12 https://www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx

**FIGURE 11.**
## Autonomous Vehicle Testing Sites Reported to NHTSA AV TEST Initiative




***Source:*** *NHTSA AV TEST Tracking Tool*


### Recommendations for Advancing Pennsylvania's Regulatory and Policy Environment to Favor Autonomous Mobile Systems Development and Deployment

- Pennsylvania should enact legislation that allows for the safe testing of SAE level 4 and 5 automated vehicles and provides a pathway to commercial deployment.
- Pennsylvania should enact technology neutral and platform agnostic policies to promote both a diverse set of autonomous vehicle (AV) use cases and a level playing field across the industry.
- Any legislation or policy should be flexible and agile enough to address industry advancements and/or new best practices.
- State legislation should reserve autonomous vehicle regulatory authority for a distinct set of coordinated state agencies (e.g., DOT / DPS) and discourage a patchwork of municipal or other local regulatory regimes.
- Steps should be taken to ensure consistency and interoperability throughout Pennsylvania.
- PennDOT should continue to be the lead state agency for Highly Automated Vehicles.

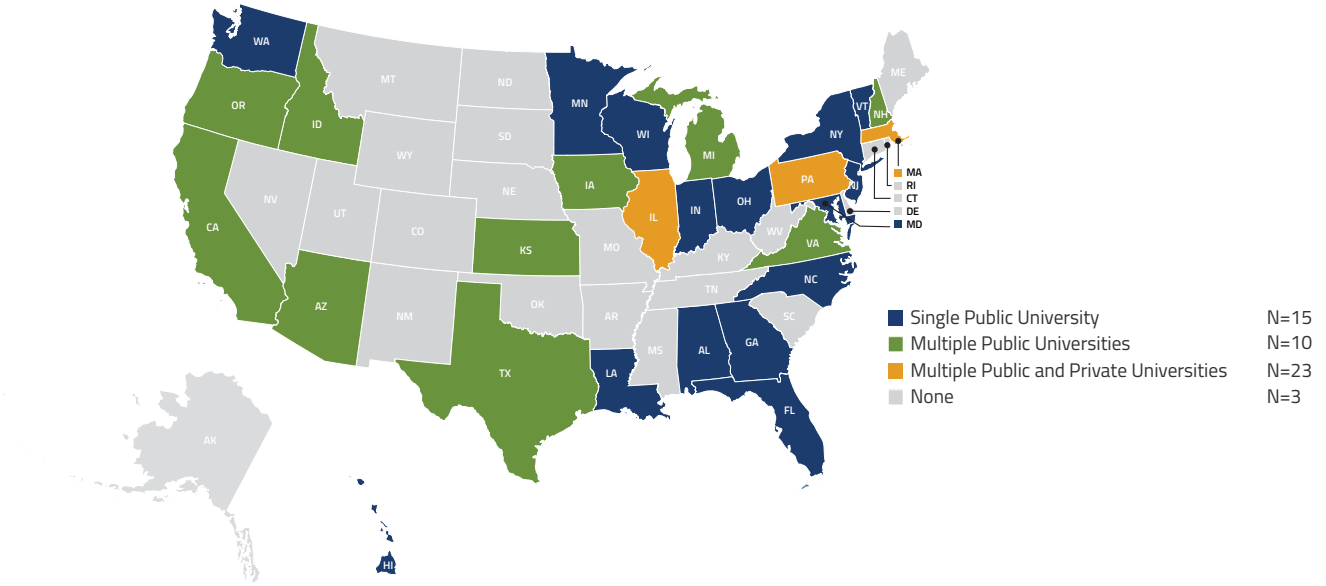
More broadly, there are additional considerations for government seeking to advance the industry opportunity. These include:

- Clear roles and responsibilities should be identified for the federal, state, and local governments that align with current jurisdiction/ governance responsibilities.
- State legislation should recognize the shared and distinct role of federal government versus state governments, e.g.:
  - The state should appropriately focus on operational excellence, human test driver qualifications and training, insurance coverage, law enforcement interaction protocols, etc.
  - Regulation of the safety of the technology/the vehicle itself should rest with the relevant federal agencies - the state should rely on company certification of compliance with such federal safety/technology rules.

## Competing for a Growing Regional Innovation Driver

While states have primarily focused on the regulatory and testing landscape for autonomous systems, several regions and cities have simultaneously been making significant investments in establishing or expanding innovation ecosystems that support the autonomy technology stack to help drive their ability to capture market share. Many regions have embedded an autonomous systems focus within their existing innovation ecosystem support programs, while others have created new organizations to help guide commercialization and foster entrepreneurial support. A review of state-level programs, actions, and organizations from 2014 to 2019 conducted by the University of California's Institute of Transportation Studies also concluded that "universities and academics are actively involved in AV actions, serving as members on committees, councils, and task forces or partnering with AV entities on research" (see Figure 12), demonstrating the additional indirect ways that regions are leveraging their research and innovation enterprises to build out a key segment of the autonomous systems industry footprint.

**FIGURE 12.**
## Academic Collaboration and Representation in Autonomous Vehicle Strategic Actions




***Source:*** *University of California Institute of Transportation Studies, Sep. 2020*

Another signal that the expanding autonomous systems industry is beginning to drive regional innovation economies can be seen in the significant amount of investment capital being deployed in support of companies focused in this space. Regions that can attract significant investment that supports innovation in autonomous systems as the industry continues to emerge are likely to be able to accelerate the growth of their innovation ecosystems, in turn creating critical mass that attracts additional investment in a virtuous growth cycle. As shown in Table 3, the Pittsburgh region has attracted an impressive share of national direct corporate investment in major autonomous systems industry applications over the last five years, totaling 18% of all U.S. dollars in mergers, acquisitions, and direct corporate investments in key autonomous systems industry verticals. However, its shares of traditional venture investment and federal support for emerging innovative companies are substantially lower, indicating that the regional ecosystem may currently be reliant on a select few market leaders (for a complete analysis of the national autonomous systems technology landscape and investment trends, see Appendix D). In order to be able to compete with other regional economies making investments in this industry across the U.S., the Pittsburgh region will need to be able to attract more of the market share of risk capital being invested in emerging companies that can broaden and diversify its industry base to build resiliency and fuel additional cycles of growth.

**TABLE 3.**
## U.S. and Pittsbugh Venture Capital & SBIR Award Activity Levels in Autonomous Systems Industry Areas, 2015-present

| | SBIR Awards* | Traditional VC Investment** | M&A and Direct Corporate Investment*** |
|---|---|---|---|
| Total U.S. Companies | 1,003 | 1,112 | 262 |
| Total Pittsburgh Companies | 15 (1.5% share of national) | 28 (2.5% share of national) | 8 (3.1% share of national) |
| U.S. Total Dollars Awarded ($M) | $1,035 | $88,447 | $42,486 |
| Pittsburgh Total Dollars Awarded ($M) | $31 (3% share of national) | $1,527 (1.7% share of national) | $7,668 (18.0% share of national) |

**Uses latest available SBIR award data, partially available through 2020 at time of analysis*
***All companies receiving at least some venture investment during time period, not including M&A and solely corporate-backed funding*
****In select verticals highly aligned with autonomous systems including Robotics & Drones and Autonomous Vehicles*
***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

### Examples of Programs in Other Regions Working to Support Autonomous Systems Innovation Ecosystems

- **Silicon Valley Robotics (SVR)** is a membership-driven coalition of robotics companies clustered in northern California that includes established companies, startups, and professional-service providers with an interest in the cluster. It operates out of its own coworking space in Oakland, and provides members with networking events, investor forums, subject matter experts-in-residence, acceleratory and startup programs, and a number of other marketing and exposure activities.
- **MassRobotics** functions as a cluster-development organization organized around a purpose-built business incubator featuring a collection of specialized prototyping and testing facilities aimed at startups in robotics and connected devices. Startup residency and programming is supported/cross-subsidized by contributions from larger companies, government agencies, and service providers. The now-40,000 square-foot MassRobotics Hub at the Boston Seaport Innovation District offers office and coworking space, access to fabrication and prototyping facilities, discounted hardware and component purchases from partners; marketing and promotion; mentor support; and event space amongst other services.
- **DriveOhio** is a formalized consortium of state agencies involved in "smart mobility," managed through an office of the Ohio Department of Transportation (ODOT) and able to contract under the latter's authority. The initiative was created by an executive order in 2018 and has partners across more than a dozen Ohio state agencies spanning multiple functions. DriveOhio and its partner agencies seed projects that attract federal grant funding, knitting together diverse state and federal assets in the interest of smart mobility advances. Through DriveOhio, the ODOT and JobsOhio committed $45 million to a new Smart Mobility Advanced Research Center (SMART Center), an automated and connected vehicle-testing facility to be built on 540 acres of the current grounds of the long-standing Transportation Research Center (TRC).
- **Mcity** is a test facility combined with an industry-sponsored research program created in 2014, all housed at the University of Michigan. The facility is a 32-acre artificial urban/suburban setting equipped with 5G vehicle-to-everything service, supplemented by an augmented reality lab that simulates traffic, "digital twins" of the physical setup, and a common API for control. Mcity claims a cumulative total of $26.5 million invested since 2015 in R&D and deployment projects, with approximately 20 active research projects that pool funds from industry sponsors. The program also involves some 50 faculty members across campus, who produce both academic publications and white papers aimed at general and industrial audiences. A collaboration with the UM College of Engineering Center for Entrepreneurship also supports student participation in mobility startups through the "TechLab at Mcity."

*See Appendix J for further detail of these initiatives.*

In order to boost their ability to attract and retain companies, talent, and investment capital, regions with significant autonomous systems industry presence across the U.S. are making investments in programmatic efforts that support their innovation ecosystems (profiles of four key initiatives being advanced by other regions of the country are described in Appendix J). Pittsburgh will face increasing competition from regions with signature state and regional initiatives that support autonomous systems applications and **must establish its own programs to reinforce its current innovation ecosystem as well as root emerging companies and talent in the region.**

## Autonomy Industry Stakeholders Have Identified Risks to Pittsburgh's Growth Trajectory

Clearly there is growing recognition of the opportunity presented by autonomous systems and competing regions are making strategic moves to position themselves to capture future growth of the industry. It is critical that Pittsburgh take a proactive stance in further building out its own industry cluster and supporting it with a more robust innovation ecosystem in order to sustain competitive advantage. Discussions with regional industry leaders and economic development stakeholders identified several areas of potential risk that Pittsburgh will face over the coming decades. These areas will require bold, forward-thinking action to mitigate the risks to future growth and reinforce Pittsburgh's position as a national leader- a position which could drive decades of future economic growth for the area once products reach mass deployment.

In order to understand the dynamics driving the region's industry presence as well as potential actions to enhance Pittsburgh's competitive position, TEConomy conducted interviews with 30 autonomous systems industry stakeholders comprised of industry leaders, research institutions, and regional innovation ecosystem organizations. These stakeholders identified several common themes that outline the risks and threats that Pittsburgh must navigate in order to realize long term success in growing the industry as a regional economic driver. These key themes that emerged from stakeholder discussions included:

- **Acknowledgement that the nascent industry will still be highly influenced by broader market headwinds.** As an emerging industry sector, Pittsburgh's autonomous systems companies will remain subject to outsized influence by global market headwinds that have the potential to shape the trajectory of future growth.

- **Concern that at a state level there is not consistency and transparency in regulatory and operating environments necessary to enable industry investment and growth,** particularly for the autonomous vehicle industry. Recommendations in this latter regard are covered on page 25 in the text box.

- **Concern that the region is viewed as an "R&D outpost" for some major companies rather than a headquarters destination,** with some companies only seeking to mine the existing academic research and innovation ecosystem through smaller branch offices without locating significant manufacturing, business support, and administrative operations within the region that drive employment gains and larger economic multiplier effects. While R&D is an extremely important activity, contributing high wage jobs to the region and sparking innovation (and its associated economic benefits) there will be significantly higher economic gains to be realized (and more diverse job opportunities created) if the region also secures the manufacturing and associated support operations that are likely to be derived from R&D success.

**30 Stakeholder Interviews Conducted**

- 16+ leading autonomous systems and robotics companies
- 7+ local business, economic development, and innovation ecosystem organizations
- Major schools and institutes at Carnegie Mellon University and University of Pittsburgh aligned with supporting autonomous systems innovation.

- **Recognition that significant portions of the components supply chain for autonomous systems are offshore** and represent a broader strategic supply issue for the U.S. that Pittsburgh cannot fully address at the regional level given existing cost and scale advantages of overseas manufacturers. Despite this larger constraint and the significant industry level of outsourcing upstream supply and manufacturing, there is still an unrealized opportunity to localize elements of the supply chain within the region. Looking at a corridor stretching from Pittsburgh in the southeast, through Ohio, and into Detroit in the northwest, there is deep expertise in manufacturing, including in automotive manufacturing, and there should be substantial opportunities to combine capabilities into a facilitated manufacturing network that may help prevent companies from automatically thinking suppliers need to be offshore.

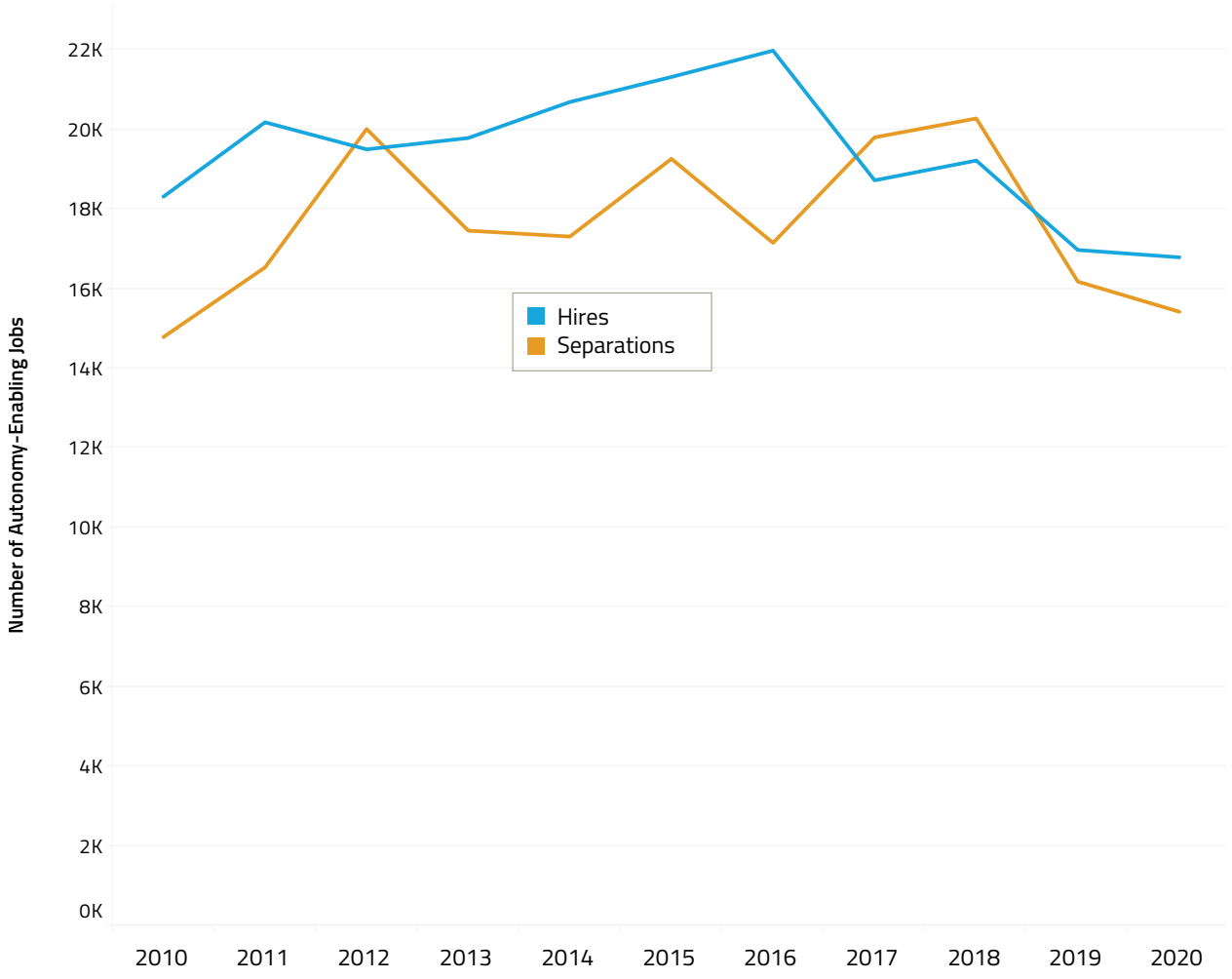
- **Current regional ecosystem organizations that are generally aware of the potential of this market space and supportive of tech-based entrepreneurial activity in autonomy, but that have programs and initiatives which are diluted and not coordinated across organizations and market verticals.** Many stakeholders identified the lack of ecosystem coordination as a key risk relative to competitor regions who have signature programs and support organizations enhancing their industry clusters and stated a key need as being able to aggregate resources and the industry voice, and coordinate the relevant programs across multiple ecosystem organizations, through a recognized "champion" organization. Currently the Pittsburgh Robotics Network stands as the main industry-focused cluster organization, but it has relatively limited resources and needs to be networked with, and supported by, other regional economic development organizations with specific programs and expertise support.

- **A perception that local venture funding gaps persist despite the autonomy industry's success in attracting investment from outside the region**, with few available options for emerging autonomous systems companies at the post-incubator/post-accelerator program stage but not yet at the level of maturity for major corporate partner investment. Companies note that, outside of the autonomous vehicles space, most of the companies in autonomous systems in Pittsburgh have expended substantial time (often cited as years) in pursuit of funds to sustain early stage operations and the capital available from Pittsburgh regional sources has been quite limited.

- **Concern that the talent supply base of the region is facing skill gaps and other growing pains** in the wake of the success of the initial cohort of autonomous vehicles companies. There are pressures on the talent supply stemming from regional competition for labor, gaps in senior entrepreneurial and tech talent within emerging companies, a limited, aggressively recruited supply of talent from CMU's graduate programs, and some notable slowing in the growth of regional autonomy-enabling occupations since 2018 (see Figure 13).

These risks to the future trajectory of the region's existing base of companies will require a multifaceted set of strategic actions that can help set the region on a path to growth and continued national leadership.

**FIGURE 13.**
Pittsburgh Region Hires and Separations in Autonomy-Enabling Occupations, 2010-2020




***Source:*** *TEConomy analysis of occupational data from Emsi (Emsi Release 2021.1)*

# What is at Stake:
## The Impact of Pittsburgh's Autonomous Systems Industry

In the face of an emerging competitive landscape seeking to capitalize on the next phase of autonomous systems industry growth, the stakes are high for Pittsburgh's current industry base and the significant economic output it provides currently and promises for the future.

To illustrate the value the industry provides to the Pittsburgh region today, TEConomy analyzed the economic impact of 71 local firms (or in cases of major multinational corporations, divisions, or operating units of those firms) that were identified as having core business operations that primarily served the autonomous systems industry. Quantifying the economic footprint of an industry relies on tying employment in industry sectors to the economic output they produce. Output is defined as the dollar value of goods and services produced by a company and summing output across all companies in an industry yields total industry output. The footprint of an entire industry in terms of its output is commonly known as the industry's economic impact and can be categorized within the context of the region's larger economic output to determine the importance in driving overall economic activity.

### The Impact of Pittsburgh's Autonomous Systems Industry Cluster

A conservative estimate of the Pittsburgh region's autonomous systems industry today includes 71 companies and 6,300 jobs which generate significant economic impacts.

- These direct jobs support more than 8,600 additional jobs through indirect and induced effects, for a total economic impact of over 14,900 jobs.
- These jobs support almost $651 million in estimated direct labor income, and $1.2 billion in total labor income.
- The industry generates an estimated $1.5 billion in direct economic output and supports nearly $3 billion in total economic output.
- The industry generates over $161 million in direct local, state, and federal tax revenues and nearly $347 million in total tax revenues.
- One employee in the autonomous systems industry sector supports approximately 2.36 additional employees in other industry sectors.

The economic impact analysis of Pittsburgh's autonomous systems industry makes use of a custom economic Input/Output (I/O) model that quantifies the interrelationships between economic sectors in the regional economy, allowing for estimation of the impacts of one sector on all other sectors with which it interacts. The measured economic impacts of an autonomous systems technology company within this model consist of three types:

- **Direct effect:** The dollar valuation of all goods and services provided as output by a company
- **Indirect effect:** The valuation of all of the inter-industry transactions between a company and other companies that supply the materials or services required to produce output
- **Induced effect:** The valuation of household income supported by the company through expenditures its employees make at other local industries.

Together, these three impacts comprise total economic impact. I/O analysis thus models the flow of funds that originate from direct autonomous systems industry expenditures in the economy and the ongoing ripple (multiplier) effect of these expenditures. In other words, economic impact models are based on the concept of the "multiplier"—that every dollar spent in the economy is re-spent one or more times, thereby generating additional economic activity and impact.

The current estimated impacts of the Pittsburgh region's autonomous systems industry were calculated using 2019 region-specific I/O models generated by the IMPLAN Group (one of two major developers of nationally and regionally-specific[13] I/O

13 The analysis region was defined as the 10-county region of southwestern Pennsylvania that RIDC uses as its target for economic development activities.

tables and analytical systems). The estimated direct employment footprint of Pittsburgh's autonomous systems firms totals over 6,300 jobs which provide an estimated $651 million in labor income, $34.7 million in state and local tax revenues, and $126.7 million in federal tax revenues. These companies generated a further 8,604 full or part time jobs through indirect and induced effects to support a total of 14,923 jobs in the region. Estimated business revenues from the autonomous systems industry added approximately $1.5 billion in business volume to the regional economy and contributed an additional $1.5 billion in business volume through indirect and induced business spending to support a total economic output footprint of nearly $3 billion dollars (see Table 4)[14].

**TABLE 4.**
**Economic Impact Results for Current Pittsburgh Autonomous Systems Industry Employment**

| Impact Type | Employment | Labor Income ($M) | Value Added ($M) | Output5 ($M) | State/Local Tax Revenues ($M) | Federal Tax Revenues ($M) |
|---|---|---|---|---|---|---|
| Direct Effect | 6,319 | $650.9 | $835.0 | $1,514.1 | $34.7 | $126.7 |
| Indirect Effect | 3,227 | $248.5 | $357.8 | $621.5 | $24.0 | $50.4 |
| Induced Effect | 5,377 | $297.1 | $505.7 | $859.4 | $46.5 | $64.9 |
| Total Effect | 14,923 | $1,196.5 | $1,698.6 | $2,995.0 | $105.2 | $242.0 |
| Multiplier | 2.36 | 1.84 | 2.03 | 1.98 | | |

The effect that direct industry spending and employment has on economic activity across all other industries in the state is known as the industry's multiplier. One employee in the autonomous systems industry today supports approximately 2.36 additional employees in other industry sectors, and every $1 in spending from the autonomous systems industry generates an additional $1.98 in economic output from other industry sectors.

This analysis represents a conversative estimate of the total economic and functional impact provided by the industry to the region, as there are additional firms not focused primarily on autonomy whose products and services still provide key enabling capacities for the autonomous systems technology stack. The analysis also does not include the potential economic impact on the wide base of existing companies located in the Pittsburgh region who could reap the benefits of autonomous solutions as they are commercialized and deployed, in turn making local manufacturing, production, business services, and other industries more innovative and competitive and driving their employment growth.

**The nearly 15,000 jobs in total employment impacts described above are being generated by an industry sector that is still maturing and largely in pre-revenue stages for many of Pittsburgh's companies (including large employers in the autonomous vehicles space).** The potential impact for the region as the industry continues to grow could scale exponentially in the coming decades. This will only happen, however, if Pittsburgh can:

- Continue to generate innovative companies advancing autonomous systems solutions
- Retain large industry employers
- Act as a site for expanding testing operations in autonomous vehicles and other mobile systems, and
- Provide an advantageous location for autonomous systems companies to grow their employment in business support, production, and other administrative and service functions (as they expand in the course of products reaching widespread deployment).

14 Some caution is warranted in interpreting the dollar amounts of total output impacts, as the impact model is being driven by employment estimates of individual autonomous systems companies as opposed to actual reported company revenues. The model assigns an average revenue per employee based on the region and its industry mix to estimate total output, which may or may not reflect the current revenue generation levels of companies.

To illustrate this latter point, consider just the market segment focused on autonomous vehicles. A 2019 study by the Boston Consulting Group and the Detroit Mobility Lab[15] estimates that the smart mobility market will generate 85,000 new U.S. jobs in autonomous vehicles and 7,000 U.S. jobs in smart-road infrastructure by 2028 across engineering, computer-related, and skilled trades occupations. If the Pittsburgh region maintains its current market share and innovation ecosystem but does not take significant action to improve its competitive position, it may be able to continue to grow organically, but is not likely to attract a significant share of these new jobs that can accelerate the growth of the cluster beyond its current R&D-focused employment footprint. In the face of competition from other states for these new jobs, the majority of which do not require proximity to universities and labs to perform operations and support services-oriented functions within the autonomous mobile systems industry, there is no guarantee that Pittsburgh will be the primary destination for ongoing growth as companies seek to find attractive environments to site their new business functions.

Moreover, even levels of future organic growth are not guaranteed to persist at the rates observed in the region over the last five years. Analyses of job postings activity and autonomy-enabling occupations indicate that growth of the talent supply may be starting to plateau (see Figure 12) and the region will face increasingly aggressive competition for a limited supply of top-tier graduates from regional institutions as well as attraction efforts aimed at local emerging innovative companies. In advance of the region's industry reaching a "steady state" growth trajectory that is more limited to the types of R&D-centric operations present today, Pittsburgh must take action to ensure that its industry remains on an accelerated trajectory instead. As the BCG and Detroit Mobility Lab study notes:

> *"If they are serious about creating or expanding as mobility hubs to boost the local economy, cities and states must be willing to become the main orchestrators of the environments they want to create. They must collaborate with academic institutions to support educational and training programs. They must be open to working with companies that are looking for incentives, such as tax breaks, to move into the area, and help companies navigate regulations governing testing, safety, certifications, and AV operations. They should also clear the way for the creation of testing grounds where car companies can try out new vehicles. Finally, they must offer the social, cultural, and recreational amenities that prospective students and people with in-demand skills want in the area where they work and live."*

These conclusions are equally applicable across the various sectors of the broader mobile autonomous systems and highlight the return on investment that proactive regions can expect to realize if they commit to supporting the growth of this industry.

Given the uncertainty around the future development of the broader mobile autonomous systems industry, accurate estimates of the potential future economic gains at stake are difficult to articulate. However, taking the AV industry as just one segment of the market that the region could be poised to attract, it is not unreasonable to think that with concerted action to enhance Pittsburgh's current competitive position as a national hub the region could attract up to a quarter of the new job gains as autonomous systems companies begin to productize their offerings. In the context of the AV industry, this could equate to more than 20,000 jobs over the next decade. Given the overall market size noted in Section 1, additional job gains from growing manufacturing, business support, and operational services employment in the region across other mobile autonomous systems markets could easily number in the tens of thousands as well.

To realize the full potential of the autonomous systems industry, Pittsburgh must commit to a set of strategies and actions targeted at enhancing the existing industry base and innovation ecosystem. The significant level of current economic impact provided by the sector is not a guarantee of future success in the face of increasing competition, and the region is at a crossroads in determining its growth trajectory for the future. Through major investment in this opportunity, Pittsburgh can position itself to break out of the current "status quo" organic growth cycle and instead put itself on an accelerated growth trajectory that reaffirms the region's innovation strengths and creates a strong technology-based industry cluster.

15 "The US Mobility Industry's Great Talent Hunt", *Boston Consulting Group and Detroit Mobility Lab*, 2019

# IV. STRATEGIC PLAN

**Pittsburgh's regional position in autonomous mobile systems can be significantly strengthened by taking bold action to invest in the opportunities presented by this cluster. Multiple strategies and actions must be implemented in a coordinated, high-commitment effort to build and sustain the complete ecosystem needed to secure Pittsburgh's leadership position and stay ahead of the competition. Actions are needed to rapidly evolve the opportunity from being predominantly R&D focused, to a diverse, full-range industry cluster that spans development of innovative new technologies all the way through the commercialization cycle of manufacturing, distribution, and service of high value products and services.**

**An opportunity of this magnitude – an opportunity to lead in a fast growth, technology sector and advanced industry – presents itself rarely and has the potential to advance the region and state's economic development for decades to come. Public and private sector stakeholders in the region and the Commonwealth of Pennsylvania must act with urgency and purpose to capture the full potential for transformative economic growth the industry represents.**

## Strategic Vision

As the preceding chapters have illustrated, the Pittsburgh region has a signature opportunity to further advance its economy, and the economy of the Commonwealth of Pennsylvania, through ongoing development and enhancement of its distinctive position in the science, technology, and business of autonomous mobile systems. Already significant and growing, the autonomous mobile systems sector in Pittsburgh presents the very real prospect of being transformative for the regional and state economy moving forward. As noted, however, the current regional position, especially in terms of R&D and associated innovation, is very strong but not without established or emerging competition from other regions.

The growth of the sector in the Pittsburgh region has, so far, been largely organic, accomplishing what has been accomplished through university and entrepreneurial R&D and commercialization resourcefulness. That ad hoc, organic growth is a laudable achievement, but it will not be enough to assure the full transformational promise of the sector for the region and the state moving forward. As we have seen, the upside potential of realizing the development of the full value-chain from R&D through manufacturing of autonomous systems in Pennsylvania would be large-scale generation of high wage jobs and a significant boost to regional and statewide economic output. Realizing that potential, however, requires a more strategic and coordinated approach be taken to meeting the full needs of this specialized industry sector and assuring the technology-based economic

development ecosystem is specifically tuned to maximize opportunities and growth. Doing this requires bringing together both public and private sector, and for-profit and not-for-profit, stakeholders to coordinate strategic activities and actions.

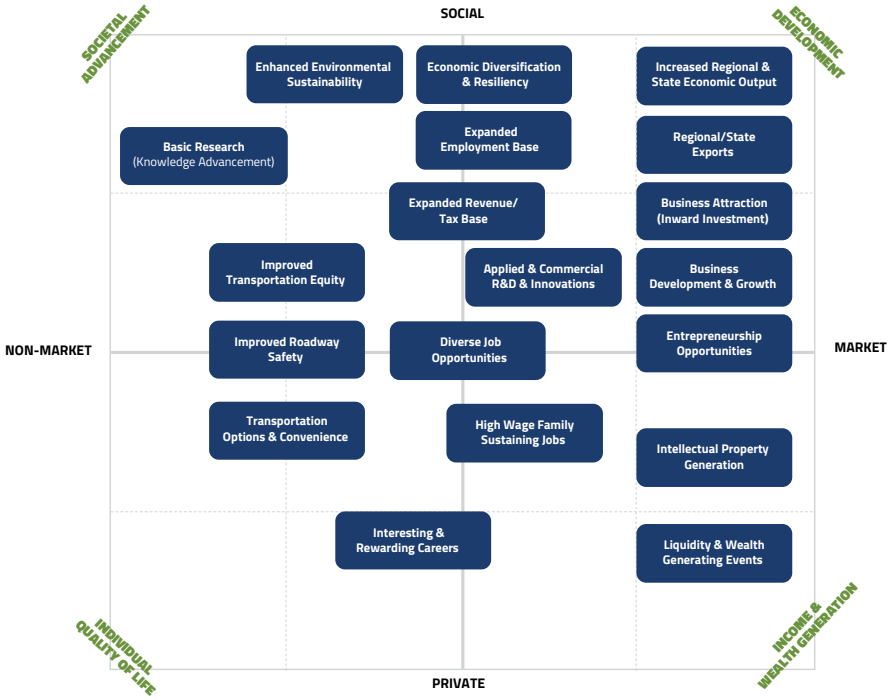
As a starting "vision" for this strategy, TEConomy believes the following to be on-point:

### Vision Statement

Driven by both world-class R&D excellence and a full-stack industry value chain, the Pittsburgh region has cemented and expanded its economic position, and global reputation, as a leading hub for innovation and advanced industry growth across diverse applications in autonomous mobile systems and associated technologies. This growth is supported by a complete and highly tuned supporting technology-based economic development (TBED) ecosystem that is responsive to and meeting the needs of the sector in terms of talent development, capital access, specialized shared infrastructure, manufacturing and supply-chain networks, supportive public policies for technology demonstration and deployment, and other key factors conducive to ongoing industry innovation and growth.

Achieving this vision will go a long way to assuring that the Pittsburgh region and Commonwealth of Pennsylvania achieve large-scale and lasting economic and societal impact benefits through an economic sector that is both poised for explosive growth and leverages distinctive tacit assets in the Pittsburgh region. The benefits to realize through implementing the recommended strategies and actions herein are anticipated to be substantial and diverse, generating multi-faceted innovation-based impacts through autonomy as highlighted on Figure 14.

**FIGURE 14.**
**Classification of Anticipated Impacts Via Autonomous Mobile Systems-based Economic Development**




***Source:*** *TEConomy Partners, LLC.*

# Strategic Plan Development

Realizing the full potential of the autonomous mobile systems sector for the region and Commonwealth will not happen on its own. Certainly, significant growth has occurred, and will likely continue to occur, organically, but the upside potential is too great to leave the fortunes of the sector to serendipity. **Some aspects of the ecosystem require shared and collaborative actions in order to achieve required conditions, and elements of the ecosystem depend not only on the individual actions of private industry, but also supporting actions within regional education institutions, public sector agencies (at the state and local level), non-profit regional economic development organizations, and other key stakeholders.**

Having a shared vision and working to implement a strategic plan to achieve that vision, is important and necessary. As a review of competing initiatives and locations in autonomous systems reveals (Appendix J), even locations such as Silicon Valley and Boston are not purely reliant on private sector actions alone. These competing hubs are organized, have well-established robotics networks, and see state and local engagement in support of their development. Similarly, places that are not yet at the level of Pittsburgh in terms of autonomous mobile system assets are not standing still, they are coordinating their efforts and investing both public and private funds and resources towards overtaking Pittsburgh and other leaders if they can. Against this background of great opportunity, and prescient threat, it would be a major mistake for the Pittsburgh region and the Commonwealth of Pennsylvania not to act strategically.

The strategic plan elements profiled herein have been developed to:

- **Leverage, further build, and complement the distinctive assets and core competencies that the Pittsburgh region has already developed in autonomous mobile systems and associated technologies.**
- **Round-out and optimize the supporting ecosystem that will enable these assets to "fire on all cylinders" in terms of realizing market opportunities.**
- **Maximize sector growth and competitive advantage in the region, such that the "sticky" position already achieved is reinforced and a virtuous cycle of investment, talent attraction, and growth achieved not only in R&D but also into manufacturing and full-scale business services.**

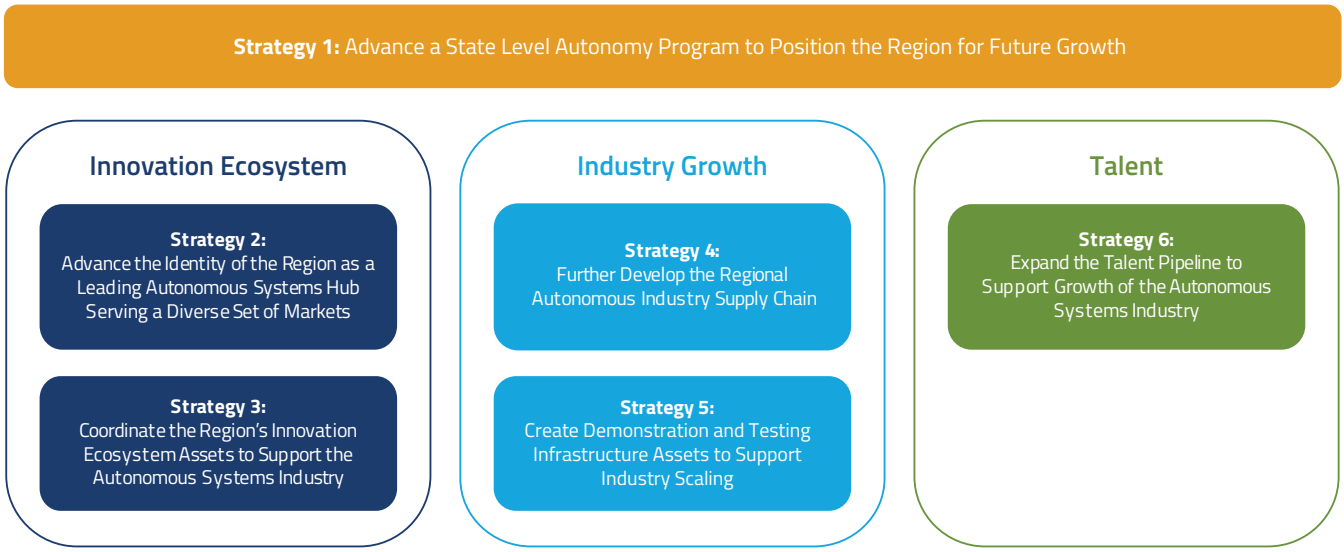
# Strategies and Action Summary

The strategic plan itself comprises six strategies and an associated set of 16 actions purpose designed to optimize the regional ecosystem for autonomous mobile systems and catalyze substantial economic growth.

The strategic plan has been developed based on multiple avenues of analysis and input received across the project. While it is prescriptive and actionable, it is also structured to have flexibility in terms of being adaptable and evolvable given that the trajectory and growth curve of various sectors, particularly in terms of timing of market acceptance and regulatory approvals is as yet indeterminate and subject to change. Because this is anticipated to be a fast moving opportunity, the strategy is intended for implementation over a two- to three-year timescale (with recognition that some actions, such as expanding graduate output, are inherently more long-term in their realization).

The recommended strategies are shown on Figure 15, indicating the crosscutting nature of advancing state support, and the general classification of each strategy by theme. The recommended actions associated with each strategy are summarized on Figure 16.

## FIGURE 15.
## Strategies for Growing Pittsburgh's Autonomous Mobile Systems Industry




## FIGURE 16.
## Recommended Actions Under Each Strategy

| | |
|---|---|
| **Strategy 1:** Advance a State Level Autonomy Program to Position the Region for Future Growth | **Action 1.1:** Develop and advance a framework for a signature state initiative in autonomy<br>**Action 1.2:** Take a proactive stance in developing forward-thinking regulatory guidance for policymakers<br>**Action 1.3:** Advance public-private smart infrastructure projects that support autonomous systems deployment |
| **Strategy 2:** Advance the Identity of the Region as a Leading Autonomous Systems Hub Serving a Diverse Set of Markets | **Action 2.1:** Develop a branding and marketing initiative that can increase both external and internal public awareness<br>**Action 2.2:** Develop a business attraction initiative targeting scaling and mid-size companies in the technology stack<br>**Action 2.3:** Attract several leading trade shows, conferences, and other high-profile showcase events |
| **Strategy 3:** Coordinate the Region's Innovation Ecosystem Assets to Support the Autonomous Systems Industry | **Action 3.1:** Support a dedicated organization that can be the nexus for regional innovation and cluster development activity in autonomous systems<br>**Action 3.2**: Address risk capital stack gaps<br>**Action 3.3**: Enhance regional support mechanisms for autonomy industry entrepreneurs |
| **Strategy 4:** Further Develop the Regional Autonomous Industry Supply Chain | **Action 4.1:** Build out a contract manufacturing and regional supply chain consortium<br>**Action 4.2:** Identify shared, noncompetitive, technology areas for collaborative industry projects and attraction of supply base |
| **Strategy 5:** Create Demonstration and Testing Infrastructure Assets to Support Industry Scaling | **Action 5.1:** Explore the potential for shared testing and demonstration projects that can serve as industry assets<br>**Action 5.2:** Implement a set of ongoing, public-facing autonomous systems demonstration projects |
| **Strategy 6:** Expand the Talent Pipeline to Support Growth of the Autonomous Systems Industry | **Action 6.1**: Expand the talent pipeline through coordination across regional institutions<br>**Action 6.2:** Address current gaps in the region's autonomy industry talent base |

# Specific Strategies and Actions

The details regarding each strategy and subsequent action are outlined in the narrative that follows.

## **Strategy 1:** Advance a State Level Autonomy Program to Position the Region for Future Growth

### Rationale

Pittsburgh is increasingly recognized as one of the leading regions in the country in autonomous systems innovation, but competition is growing as large facilitating infrastructure and strategic investments in autonomous technologies are made elsewhere. The level of economic opportunity presented by autonomous mobile systems in the Pittsburgh region is of a level that warrants strategic investment of Commonwealth funds to help build-out the supporting ecosystem and accelerate Pennsylvania's industry trajectory to stay ahead of the competition. As impact analytics show, such action can cement the already 6,266 job presence of the sector currently and build momentum for much larger scale employment and economic impacts over the next five years.

**The need here is to think big – to cement Pittsburgh's already strong R&D-driven position by giving it the signature supporting infrastructure, assets, environment, and policies that will make it the best location to develop, test, and produce autonomous mobile systems.** A strong collective voice of the industry is required here to communicate what is needed, but part of the problem has been that this collective voice has not yet been facilitated through a robust shared organization that convenes key stakeholders. That is emerging now with the **Pittsburgh Robotics Network** (PRN) under new leadership and building momentum (discussed further under Action 3.1), but PRN is still growing and has limited human resource capacity to cover implementation of the full strategy outlined herein. **The other missing element has been a focused initiative at the State level, that would put the full force and resources of the state behind advancing autonomous mobile systems as a key strategic imperative.** Multiple other states have made this commitment, with neighboring Ohio a prime example of a state-led initiative convening key stakeholders to provide coordinated actions designed to grow an autonomous vehicles and smart mobility cluster in Ohio (a state with substantial existing position in the automotive manufacturing sector that it seeks to protect and leverage). The Ohio initiative, DriveOhio, has partners across more than a dozen Ohio state agencies, and it seeds projects that attract federal grant funding, knitting together diverse state and federal assets to advance smart mobility. The commitment of state funds is considerable, as evidenced by the fact that through DriveOhio, the Ohio Department of Transportation and JobsOhio committed $45 million to a new Smart Mobility Advanced Research Center (SMART Center), an automated and connected vehicle-testing facility to be built on 540 acres of the current grounds of the long-standing Transportation Research Center (TRC). Other states and regions are also being aggressive in their pursuit of the opportunity and putting in place clear and transparent policies that enable autonomous vehicle companies to test full autonomous systems in public settings.

Pittsburgh's already strong, and highly promising, autonomous mobile systems cluster needs to be supported by a similarly strong commitment by the Commonwealth of Pennsylvania to building the public infrastructure and a regulatory framework that is optimized to promote advancement of this transformational R&D and industry cluster in the state.

## Action 1.1: Develop and advance a framework for a signature state initiative in autonomy

The potential market opportunity requires a bold, visionary state-level initiative that can help solidify the region's position as a hub for autonomous systems. The Commonwealth of Pennsylvania needs to commit significantly, across multiple dimensions, to:

- **Coordinate state resources and agencies, in a structure similar to DriveOhio, to advance a pro-autonomous mobility agenda in the state and prioritize investments that can leverage state funding to secure further significant federal funding.** It is recommended that the Governor's office and PennDOT create a central hub for coordinating activities between state and local agencies, industry partners, and other stakeholders conducting work related to the autonomy industry, **ideally located and staffed in Pittsburgh**. This initiative should also collaborate with DriveOhio to coordinate further the vision of the multi-state Smart Belt Coalition (MI-OH-PA).

- Provide strategic state investments in signature infrastructure projects and autonomy focused initiatives in the Pittsburgh region, particularly focused on:

    - **A multi-purpose, multi-user test and demonstration facility for autonomous mobile systems to be located within the City of Pittsburgh or close adjacent municipality** that is highly convenient for use by the existing cluster of businesses, the university cluster in Oakland, and emerging entrepreneurial enterprises. (See Strategy 5)
    - **Co-locate a robotics business incubator facility** (similar to the operations of Mass Robotics – see Appendix J), with shared resources and supports, at, or close to, the site of the demonstration facility. Establishing this with adjacency to, or co-location with, the Robotics Innovation Center being developed by Carnegie Mellon with RK Mellon Foundation funding would leverage the foundation/university investment, which is partly focused on making Hazelwood Green a concentrated R&D and manufacturing development hub in advanced robotics. (See Strategy 5)
    - **Support the establishment of geofenced demonstration corridors** using public road infrastructure to assist in the ongoing development of autonomous vehicles and smart mobility technologies. (See Strategy 5)
    - **Provide initial funding for attracting, or developing, a contract manufacturing center and manufacturing network in the Pittsburgh region** that will provide a convenient domestic option for companies to work with as they scale their products and develop strategies for manufacturing key systems and subsystems necessary for robotics product advancement. (See Strategy 4)

- **Develop and fast-track a clear pathway for full autonomous transportation deployment** that is competitive with other states that are already allowing fully autonomous testing on state and municipal roads (See Action 1.2)

- **Provide an operational funding support grant to the Pittsburgh Robotics Network** to support its further development and growth as the industry-facing cluster-based autonomous systems development organization in the region and assist in its marketing of the region and Pennsylvania as an optimized location for businesses in autonomous mobile systems. (See Strategy 2).

- **PennDOT and the Pennsylvania Turnpike should commit to being early adopters of autonomous solutions for construction projects, roadway maintenance, and smart traffic management**. Procedures and public agency guidelines should be developed that are favorable to early testing and adoption of autonomous technologies by state agencies, and for the state to participate in facilitating the piloting of autonomous technologies in state funded infrastructure projects (for example, in road and bridge building projects, highway maintenance, etc.).

## Action 1.2: Take a proactive stance in developing forward-thinking regulatory guidance for policymakers

Pennsylvania needs to adopt policies that will favor the ongoing development and testing of autonomous vehicles on public roads and articulate a clear pathway for companies to follow in moving to full autonomous operations.

Balance is required in considering aspects of public safety and the development and roll-out of autonomous vehicles. While achieving 100% reliability and safety in autonomous operations is an understandable reach goal, this needs to be contemplated against the fact that human operated vehicles are generating very significant injuries, deaths, and financial losses on public highways. In 2019, PennDOT reports that there were 125,267 reportable traffic crashes in Pennsylvania and that these crashes claimed the lives of 1,059 people and injured another 76,243 people.[16] On average, a person dies in a road accident every 8 hours in the Commonwealth of Pennsylvania, and human error is the usual cause of these events. Autonomous vehicles provide a pathway towards safer roads, with computational systems promising near instantaneous reaction times, observed speed limits, best-practice based driving skill/vehicle handling in the case of avoidance maneuvers, and a "driver" who will never be tired, distracted, or under the influence. Developing policies that are favorable to rolling out autonomous systems on an expedited timeline in Pennsylvania is very likely to result in considerable public safety gains, while at the same time helping Pennsylvania rapidly advance its leadership position in autonomous systems and secure substantial economic gains.

Certainly, there will be edge cases encountered as autonomous vehicles roll-out. Autonomy is difficult and systems are built upon experience-based algorithms, programmed to act appropriately and ethically in challenging driving conditions. While edge cases will be encountered, it is important for policymakers to recognize that "perfect should not be the enemy of the good" and that some unforeseen events will likely occur, but the positives will significantly outweigh these. A vaccine, for example, can have edge cases in which adverse drug reactions occur in a very small number of individuals, but the overall public health good of the vaccine far outweighs these rare events. The fact that 76,243 people were injured and 1,059 killed in 2019 sets parameters for autonomy to be "better than." Regulators need to consider a "significantly better than" case, not the perfect case, in terms of accommodating autonomous systems testing and deployment.

As companies make investments in the development of autonomous mobile systems, they need to be able to make those investments in a predictable and transparent regulatory environment that sets clear milestones and performance parameters that are rationally rooted. The Highly Automated Vehicle Advisory Committee serves as an important public/private interface for dialog between various stakeholders and PennDOT in developing requirements for testing and deployment of autonomous systems on public highways. It is important that recommendations developed be not overly burdensome or restrictive and be competitive with other states. While public safety is a governmental responsibility, evidence suggests that autonomous driving systems represent a step towards safer roads and enhanced public safety. Pennsylvania should try to be at the forefront of realizing these benefits and helping the industry scale. Clear

### The Pennsylvania "Highly Automated Vehicle Advisory Committee"

The HAV Advisory Committee was created through Act 117, which was signed into law on October 24, 2018. The HAV Advisory Committee has the power to advise and consult the Secretary of Transportation on each aspect of highly automated vehicles and platooning in this Commonwealth and may undertake any of the following activities:

- Developing technical guidance.
- Evaluating best practices.
- Reviewing existing laws, regulations, and policies.
- Engaging in continued research and evaluation of connected and automated systems technology necessary to ensure safe testing, deployment and continued innovation in the Commonwealth.

*Further details on the work of the HAV Advisory Committee may be found at: https://www.penndot.gov/ProjectAndPrograms/ResearchandTesting/Autonomous%20_Vehicles/Pages/HAV_Advisory_Committee.aspx*

16 Pennsylvania Department of Transportation. 2019 Pennsylvania Crash Facts and Statistics.

and reasonable regulations governing autonomy that encourage innovation across a broad spectrum of potential applications will cement the state as a thought leader, driving business attraction and positioning the state as a leading deployment hub. While allowing for driverless testing and a clear path to deployment is critical, Pennsylvania legislators should also reserve autonomous vehicle regulatory authority for a distinct set of highly coordinated state agencies (e.g. PennDOT and DPS) and discourage a patchwork of municipal or other local regulatory regimes. Developing these policies/regulations and enacting them in Pennsylvania should be a high, fundamental priority, with a target set of achieving this by the close of 2021. Topline recommendations for action are included on page 25.

It is important to remember that each level of government has a role to play in the regulation and promotion of AVs. The federal government should maintain its regulatory authority over the design, construction, or performance of automotive vehicles and apply that same authority to the regulation of highly automated vehicles. States should regulate the testing and deployment of self-driving vehicles on their roads. Local governments should support the testing and deployment of self-driving technology by exploring the application of AVs in their communities, finding ways to collaborate on common goals, and considering updates to infrastructure and relevant ordinances.

## Action 1.3: Advance public-private smart infrastructure projects that support autonomous systems deployment

The development of autonomous vehicles currently is being pursued by companies whose principal goal is to make their vehicles work with current road conditions and infrastructure. This is a very logical approach for companies who are seeking to get their products into market on an expedited timeline, because there would be significant delays and only patchwork operational geographies if their vehicles required new infrastructure. That said, there will be many future efficiencies that may be realized by parallel development of smart road and municipal infrastructure, for example:

- We have all sat at red traffic lights when there are no other vehicles at, or approaching, the intersection. This wastes time and fuel and has an environmental impact. Smart traffic lights triggered by approaching vehicle communications can smooth the flow of traffic considerably.
- Smart highway lighting can save energy by only illuminating in advance of a sensed or communicating vehicle approaching the area.

Allegheny County is, in many respects, a particularly challenging development environment for autonomous vehicles because it comprises so many individual municipalities. This creates wide ranging variation in local road markings, signage, parking rules, curb structures, etc. While this presents challenges, it also provides a rich environment for experimentation in the modification of municipal practices to better accommodate autonomy and for collaborative multi-municipality development of pilot and demonstration smart infrastructure projects. Downstream benefits will be realized for the region because a more efficient city enabled by smart vehicle infrastructure is likely to be one offering more equitable transportation solutions, a healthier urban environment, enhanced public safety, less congestion, shortened commute times, better maintained infrastructure, and more.

### Traffic21 Institute

*Traffic21 is a multi-disciplinary research institute of Carnegie Mellon University. Its goal is to design, test, deploy and evaluate information and communications technology based solutions to address the problems facing the transportation system of the Pittsburgh region and the nation.*

*The Pittsburgh region serves as a "learning lab," deploying solutions that can be applied around the nation and the globe. Traffic21 leverages Carnegie Mellon's leadership in relevant areas such as intelligent transportation systems, smart infrastructure, cyber security, human factors, artificial intelligence, data analytics, and connected and automated vehicles.*

*Traffic21 Institute, Carnegie Mellon University. https://traffic21.heinz.cmu.edu/*

The benefits of smart infrastructure interfacing with autonomous systems are such that smart city solutions themselves represent a significant potential market. Recent market research places the anticipated size of the global smart traffic management market to reach $47 billion by 2025.[17] There are currently parallel technology development paths in AVs, other unmanned transportation systems, and smart infrastructure that will eventually converge across a connected ecosystem, and it certainly makes sense for the Pittsburgh region to stay ahead of the curve in terms of technology development and realizing economic opportunities out of this full future ecosystem.

Pittsburgh has multiple assets and innovative organizations that should be used as a base for expanding its autonomy-aligned infrastructure through public-private funding. A key asset to leverage is Carnegie Mellon's Traffic21 Institute (see sidebar). It would also be advisable to expand the Platform Pittsburgh Smart City Research Testbed assets to build out the "living laboratory" capabilities of the city.

Public/private investment is needed because industry alone faces high levels of risk in focusing on technology development that requires implementation and purchasing by a very broad variety of public sector bodies, with highly variable decision making processes, budgets, and priorities. Regional investment in incorporating new traffic enabling systems infrastructure, such as dedicated short-range communications (DSRC) technology or vehicle-to-infrastructure (V2I) systems, into existing assets would help position the region as a premiere testing location.

It is recommended that, under this action, the PRN form a collaborative committee with participation of the Traffic21 Institute, the City of Pittsburgh, Allegheny County, and the Allegheny League of Municipalities, together with the leading AV companies in the region, to develop a near term vision for parallel technology development and for piloting smart infrastructure deployment projects within the region. The group should also work to identify gaps and opportunities in current infrastructure needed to be addressed to support a broad portfolio of autonomous systems deployments in the region. New infrastructure projects in the region should incorporate guidance from the committee and other regional experts on needs for future autonomous systems deployment.

## **Strategy 2:** Advance the Identity of the Region as a Leading Autonomous Systems Hub Serving a Diverse Set of Markets

### Rationale

The diversity of autonomous systems applications is a key strength for the Pittsburgh region, but most public and investor attention is currently focused on autonomous cars due to large influx of capital investments. While the success of the AV sector has fueled the recognition of the region as an autonomy hub, the opportunities for Pittsburgh are clearly distributed across a much broader suite of mobile autonomous systems sectors. Diversity in sectors is a strength, spreading out risk and widening opportunities across specialty markets that each are sizeable, and which potentially offer an earlier path to market than autonomous on-road vehicles. Industry opportunities and talent interests are diverse. For example, promoting opportunities in autonomous mobile systems in applications such as construction, agriculture, mining, logistics, defense, etc. broadens the pool of companies that may be attracted or grown in the region and widens the potential talent pool to draw from. Realizing this opportunity requires developing and implementing a communications and marketing strategy that "tells the Pittsburgh autonomy story" in both cross-cutting and niche sector specific ways.

The opportunity for Pittsburgh is large, but it is also time sensitive. Other locations are organizing to pursue the autonomous systems opportunity, and the time to tell the Pittsburgh story is now. It is also important to assure the local and regional

17 Adroit Market Research. "*Smart Traffic Management Market by Component, Solutions, Services, Systems, and by Region, Global Forecast 2018 to 2025.*" October 2020. https://www.adroitmarketresearch.com/industry-reports/smart-traffic-management-market

population understands the great opportunity the region has to be a leader in a fast growing advanced industry and the economic opportunities that are associated with it. There needs to be robust public support built for on-road testing, geofenced corridors, etc. to avoid public push back on any issues that may be encountered through edge cases or other events. Public support is also important in terms of helping to build political capital for public investments to support the sector.

## Action 2.1: Develop a branding and marketing initiative that can increase both external and internal public awareness

In performing interviews it became clear that there exists no shortage of fascinating technologies and applications for autonomous mobile systems under development in Pittsburgh. Certainly, the advancement of autonomous on road vehicles via Argo AI, Aurora, and Motional (and the major automotive OEM partnerships) are a key component of messaging – communicating the power and promise of Pittsburgh in terms of its ability to attract leading household automotive names (companies that could invest anywhere) to select Pittsburgh based on its special autonomy core competencies and ecosystem assets. But other areas also are compelling:

- The automation of logistics and warehousing tasks, with products already developed and being assembled and delivered to customers out of Pittsburgh.
- The work of Locomation in autonomous relay trucking convoys, a brilliant innovation that can double the productivity of the trucking industry.
- Robotic laser based systems, by Titan Robotics, efficiently removing the paint from multi-million dollar aircraft.
- Advanced Construction Robotics' huge mobile robots that move across bridge construction projects performing the repetitive task of rebar tying, and soon rebar laying.
- Caterpillar's development in Pittsburgh of autonomous mining trucks that are already well-proven and have successfully driven millions of completely autonomous miles.

Because the Pittsburgh region is so innovative within its corporate autonomous systems sector, and because Carnegie Mellon and NREC are advancing so many interesting projects, there will be continuous momentum in announcements and stories to tell though marketing. The diversity of capabilities is a strength, but it also presents a branding challenge that needs to be addressed.

Ideally, there needs to be an "umbrella" brand that spans the full scope of the opportunity – a brand that can be used by any autonomous mobile system sector or sub-sector that operates in the Pittsburgh region. "Roboburgh," which has been tried is an example of this, but it may not be optimal. This needs the attention of a professional branding firm to develop compelling branding. It will also be the case that having the ability to have sub-brands, attached to the main brand that are geared to the specialized sub-sectors of Pittsburgh autonomous mobile systems in logistics and warehousing robotics, construction robotics, etc. should be incorporated. Whatever the brand(s) developed, it will be critically important that all engaged in the ecosystem and promoting the Pittsburgh region commit to using it, exclusively. The term "autonomous mobile systems" is used in this strategy, but that is purely for descriptive use in this technical document. Something marketable needs to be developed to describe the sector.

Because the opportunity needs to be acted upon soon, brand development should be one of the most immediate actions taken under this strategy. In parallel, a tiered marketing strategy must be developed that incorporates:

- Use of the branding in a major roll-out and its ongoing use across PR activities.
- A digital marketing campaign that targets key market verticals.
- Development of a focused website and associated collateral materials providing introductory and in-depth communication of the companies and ecosystem assets that make Pittsburgh a uniquely productive and world-leading environment for autonomous mobile systems.

It is also recommended that the Pittsburgh International Airport's natural funneling of passengers to the airside-to-landside transit system be used as a key communications and messaging location, and that several robot system examples be located there performing visible tasks and promoting interest.

It should be noted that one of the challenges to be anticipated in branding and marketing the sector is how to position it so that it is not perceived as "robots taking over and destroying jobs". Within the region, it should be relatively easy to communicate that this will be a large-job generator (it already is) in terms of the R&D and production of autonomous mobile system technologies, but as one radiates out from Pittsburgh the perception needs to be avoided, somehow, that Pittsburgh is the place developing technologies that are coming to take your job. The technology space needs to be positioned as keeping the U.S. on the leading edge of productivity and international competitiveness, and a major job generator in terms of developing technologies that will be used and exported around the world.

It is recommended that the PRN work in partnership with the PRA to coordinate the marketing of the sector and sub-sectors, and that funding support be obtained to retain a professional branding and marketing firm.

## Action 2.2: Develop a business attraction initiative targeting scaling and mid-size companies in the technology stack

It is usually the case that technology sectors that geographically cluster in specific locations are the result of the growth of local, usually entrepreneurial business enterprises. This has certainly, in-part, been the case in the Pittsburgh region, with multiple companies in the autonomous mobile systems stack being locally grown start-ups (often seeded by Carnegie Mellon/NREC developed technologies). It is also the case, however, that the special assets of the Pittsburgh region (especially in terms of the R&D and talent in associated fields contained within Carnegie Mellon University and its ecosystem) have proven to be powerful attractors for inward investment, whereby R&D centers and other operations have been located in the region by businesses headquartered outside of the region, including major international companies. Pittsburgh has proven itself able to attract significant operations to invest in the region, with relevant examples including Caterpillar, Robert Bosch, Siemens, Uber, etc. Major capital inflows have also been derived by large companies investing in the companies birthed and growing in the region.

Momentum has been built in attracting companies in the autonomous mobile systems stack to locate in Pittsburgh, but there is plenty of room for more. In some significant autonomy market verticals Pittsburgh has only a handful of companies (in construction robotics and agricultural autonomous systems, for example) and more business development and attraction is desirable to attain critical mass in these verticals. There are also gaps in the technology stack where it would be useful to attract inward investment, and there is certainly a need to build capacity in contract manufacturing – working to build out a much more robust regional supply chain for advancing the sector beyond R&D.

Having a larger base of companies is also desirable from a labor attraction standpoint. When there is an observable critical mass of companies in a location that matches the educational attainment and skills of in-demand talent, these individuals are more likely to select employers within a region that provides multiple opportunities (including the opportunity to move between employers, if need be, without requiring another relocation).

The PRA is Southwest Pennsylvania's dedicated inward investment marketing organization and should be in-the-lead on this action, working in partnership with the PRN to market and promote the region to potential company investors. The PRN should be particularly focused on working with autonomous mobile systems companies in the region, and other ecosystem stakeholders, to identify gaps in supply chain and technology stack that represent opportunities to fill through inward investment attraction. The PRA should recruit a sector marketing specialist to work with the PRN in proactive marketing outreach to targeted external companies, and the PRN will play an important role with the PRA in assuring potential inward

investors are welcomed, introduced to regional robotics leaders, and exposed to the full range of specialized assets for their sector that exist within the region.

Having convenient sites, ready to go and suited to the needs of companies in autonomous mobile systems (flexible/hybrid spaces that incorporate office space plus garage/high bay space) will represent an important attraction asset. RIDC is the obvious organizational lead for assuring that site development occurs, ideally at sites in areas where robotics companies are already clustering (Lawrenceville and the Strip District and Hazelwood Green).

The key incentive for companies to locate operations in Pittsburgh should be access to key ecosystem characteristics that will promote their business success. These will include:

- Access to talent – at Carnegie Mellon and other regional institutions, and more broadly within the industry ecosystem.
- Access to an ecosystem of potential collaborating companies and a supply chain for key technologies and services needed.
- Space in an industry-clustering location, ideally within an innovation district offering multiple amenities.
- The presence of a one-stop-shop and well-coordinated and networked ecosystem that will enable them to quickly integrate into the Pittsburgh ecosystem and leverage its advantages.

Packaged appropriately, these advantages of locating in the Pittsburgh region should provide a sufficient "attractor" such that other typically deployed business location incentives (such as tax abatements, subsidized rent, co-investment in the business venture by public funds, etc.) will not be necessary.

### Action 2.3: Attract leading trade shows, conferences, and other high-profile showcase events

The Pittsburgh ecosystem contains so much in terms of autonomous systems assets that can be visited and observed that getting people in the industry from outside to visit the region should be a priority. Similarly, the recommended investments in additional physical infrastructure outlined in this strategy will provide high visibility assets for visitation. While some of this visitation will occur through the inward investment marketing activity conducted by the PRA/PRN under Action 2.2, there is also significant benefit to be gained through development of events in Pittsburgh likely to attract larger-scale audiences. Signature trade show events are the most logical pathway to providing this mass visitation exposure. This may be accomplished through either incentivizing an existing domestic or international convention or trade show event to select Pittsburgh as a location for future events, or through development of a new event/show.

To further advance this action it is recommended that the PRN work with MeetPITTSBURGH (a division of VisitPITTSBURGH) which is SW Pennsylvania's professional convention and visitors bureau organization. The MeetPITTSBURGH team has long-standing expertise in the professional recruitment and organization of conventions and special events. It is also recommended that PRN meet with leadership of the Society of Automotive Engineers (SAE), headquartered in Warrendale, to gain their insights into event development (given their long-standing annual SAE convention and expo in Detroit) and to examine opportunities for hosting a subsidiary event in Pittsburgh, focused on autonomous mobile systems.

## **Strategy 3:** Coordinate the Region's Innovation Ecosystem Assets to Support the Autonomous Systems Industry

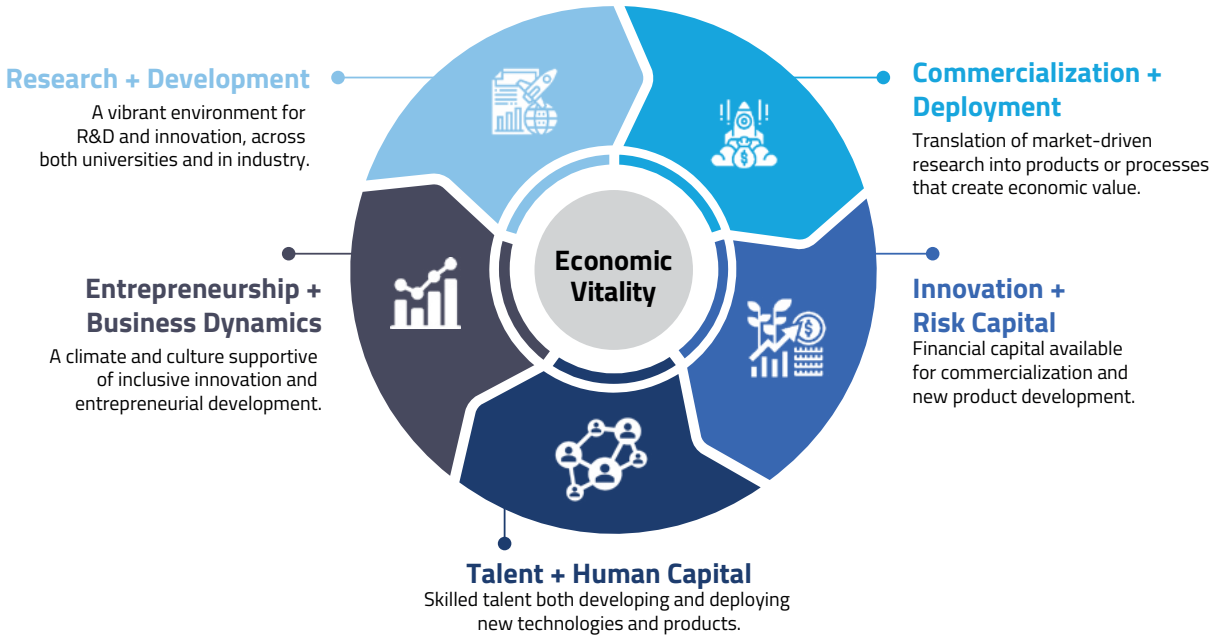
### Rationale

Regions across the nation that are achieving technology-based economic development success have one thing in common— a mature innovation ecosystem. These ecosystems may form naturally over time (as occurred in Silicon Valley and Boston); or they may result from dedicated activities of states, regions, and key stakeholders to proactively foster this ecosystem (as occurred in the Research Triangle area).

Successful innovation ecosystems are able to catalyze a variety of economic activities, including assessing the potential markets for R&D-driven capabilities and innovations against current products in the marketplace, developing new products by optimizing engineering and design to meet the marketplace's price points, developing effective management teams to drive business growth, and securing access to financial capital that will fund not only the development of the technology but also the firm through its various maturity stages until it becomes an established company in broader domestic and global markets.

A robust innovation ecosystem is at the core of the Pittsburgh Region's ability to cement its national position in autonomous mobile systems. Innovation ecosystems consist of five interconnected elements, each of which plays a vital role in developing new value-added products and services that create strong economic impacts (Figure 17).

**FIGURE 17.**
**Elements of a Robust Innovation Ecosystem with Capacity to Impact Economic Vitality**




***Source:*** *TEConomy Partners, LLC.*

Complex and challenging to develop and manage, if any element of this ecosystem either inadequately addresses economic needs or is missing altogether, the growth potential from innovation and emerging new business ventures can be stifled. Therefore, it is critical for any region to coordinate the innovation assets that it has and develop initiatives/efforts to fill ecosystem market gaps.

The Pittsburgh Region has, to its advantage, a number of innovation ecosystem assets across two primary dimensions:

1. Regional sector growth has been largely organic and driven by cohorts of CMU/NREC alumni. A shared institutional pathway to their commercial careers has built informal networking between CEO's, CTO's, and other sector leaders, but this has not consolidated yet into a well-supported shared "champion" organization providing a voice for the industry that has robust influence in the region and state.

2. Southwest Pennsylvania is served by a broad range of economic development organizations, some long-standing, and some evolutionary or relatively new. There is somewhat of a patchwork quilt of organizations which entrepreneurs and others need to navigate to identify available services and programs that will support their business growth, and many of the existing support organizations do not have programs that are specifically geared to the specialized needs of the autonomous mobile systems sector.

What is lacking currently in the Pittsburgh Region is a coordinating effort that leverages the region's innovation ecosystem assets to support the autonomous systems industry. The sector needs to have a clear point of contact for those seeking to engage with the ecosystem. Having a high-profile organization focused on meeting the needs of industry, coordinating existing ecosystem assets, and driving forward the implementation of the strategic plan will be critical to the success of the strategy. Other regional organizations need to recognize and be fully supportive of the efforts of the autonomy organization, providing resources, expertise, and services in support of its activities.

## Action 3.1: Support a dedicated organization that can be the nexus for regional innovation and cluster development activity in autonomous systems

When a region is presented with an opportunity to scale a significant cadre of assets and businesses into a distinctive advanced technology cluster, best practices indicate that there needs to be a dedicated and focused organization that acts as "connective tissue" for the cluster. Having an organization that is solely focused on the specialized needs of the cluster has numerous advantages:

- It allows pure concentration on the needs of the cluster without dilution of attention or programs to other business sectors – including at a board level within the organization
- It allows a team to be built to service the cluster that has specialized knowledge
- It provides a key single-point of contact for businesses, entrepreneurs, investors, job-seekers, and other stakeholders interested in the sector
- It becomes a vehicle for coordination of other R&D, innovation, business incubation and

### Case Study: BioCrossroads as an Exemplar Cluster Collaborative

In 2002, analytics by Battelle indicated strong core competencies and growth prospects for Central Indiana (the Indianapolis region) focused on life sciences. The region. Led by the Central Indiana Corporate Partnership (CICP), embarked on an ambitious program to connect key bioscience ecosystem organizations, and advance a purpose built initiative to focus on cluster growth. Corporate, government, academic, and philanthropic stakeholders collaborated to develop and advance a strategic action plan, forming the Central Indiana Life Sciences Initiative (CILSI) to advance implementation. In 2004 CILSI was renamed BioCrossroads – a brand that communicates both the central location of Indiana in the U.S. and the collaborative focus of the organization.

BioCrossroads has proven to be a highly effective catalyst for regional growth, helping to expand the cluster into a $44 billion driver of the regional economy. Noted urban specialists Bruce Katz and Jeremy Nowak in their book "The New Localism" specifically highlight BioCrossroads for its scope and effectiveness in growing this industry – highlighting CICP and BioCrossroads as a global model for communities in structuring and governance of economic development activity.

*Further narrative of BioCrossroads evolution as a leading cluster-based economic development organization can be accessed at: https://biocrossroads.com/the-evolution-of-biocrossroads-2002-2012/*

acceleration service providers, across the broader tech ecosystem (and for collaborations between providers to serve the needs of the sector)
- It gels into a trusted organization for centralizing networking, seminars and educational events, events, job fairs, etc.

Multiple successful examples exist of such focused TBED/cluster organizations, such as:
- The North Carolina Biotechnology Center
- Multiple focused and freestanding organizations under the Central Indiana Corporate Partnership (CICP) such as BioCrossroads (life sciences), AgriNovus (agricultural sciences), Conexus (logistics and advanced manufacturing), and TechPoint (IT and software)
- The Water Council, in Wisconsin focused on water industries and associated technologies, and Chicago's Current organization for their water cluster
- Iowa's Global Insurance Accelerator focused on insurance and FinTech cluster development
- The Bluewater Wood Alliance with 100 members who make up the advanced wood manufacturing sector in Ontario.
- The Maritime Alliance in San Diego focused on maritime technologies and workforce development
- Mi-Light focused on growing Michigan's photonics industry
- MassRobotics and the Silicon Valley Robotics in the robotics and autonomous systems spaces.

Such organizations vary in their structure from predominantly state supported through legislative funding (e.g. the NC Biotech Center) to independent non-profit institutions and membership organizations. What they share is a specialized knowledge of their sector and a dedicated focus to making their sector of focus grow.

Interviews with Pittsburgh region robotics and autonomous systems companies indicated that the leadership of these companies are generally supportive of the existing **Pittsburgh Robotics Network (PRN)** as being the foundation for such organizational focus in the Pittsburgh region. A grassroots, largely industry-led organization (and including Carnegie Mellon representation on its board), the PRN operates as a membership-based consortium. Led by Joel Reed (experienced in the industry and former CEO of IAM Robotics) and steered by a board of industry leaders, the PRN is suitable as a base from which to build and to work in partnership with existing regional economic development ecosystem organizations..

### The Pittsburgh Robotics Network – Key Facts

As of late July 2021, the PRN reports having 80 members that are robotics companies and 100+ ecosystem members. The budget for the organization for FY2021 is $700,000 (of which $360,000 had been secured by mid-July).

Primary sources of revenue for the PRN are: 1. Sponsorship revenue (Leading/Founding Sponsors, Annual Sponsors, Event Sponsorship), 2. Foundation support, 3. Membership revenue (external stakeholders), 4. Ticket revenue, 5. Miscellaneous.

The PRN operates with only three personnel currently, but anticipates having five total by the end of 2021 with the following positions:

- Executive Director
- Director of Programming
- Event Coordinator
- Special Events & Industry Programming (this is for annual events & a larger conference, the latter which will require an expanded team or outsource manager)
- Community Engagement Manager

PRN currently outsources design, web, marketing, social media & PR activities, and has identified future need for an in-house marketing/content developer and a talent initiatives program manager.

Ideally, PRN, if more fully funded and further expanded, could form the center of a hub and spoke model for the autonomous mobile systems cluster that would coordinate and link various existing TBED resources and not be duplicative of them. Organizations including the Pittsburgh Technology Council (PTC), Innovation Works (IW), Catalyst Connection (CC), the Pittsburgh Regional Alliance (PRA), and the Regional Industrial Development Corporation (RIDC), occupy specific economic development ecosystem areas that will be critical to supporting autonomous mobile systems cluster needs in terms of:

- Public policy, advocacy, and access to shared services core competencies (PTC)
- Early stage capital, entrepreneur mentorship, and networking (IW)
- Business development and advancing products to manufacturing (CC)
- Regional and sector marketing and inward investment attraction (PRA)
- Regional strategic business site development and infrastructure (RIDC).

The RIDC is a good option as an organization for incubating the PRN, able to provide office space and basic support services. RIDC can also help to organize and mentor the organization as it navigates the opportunity to become a significantly larger and more influential organization serving a central role in strategy implementation, ecosystem development, and cluster development coordination for the autonomous mobile systems sector. A commitment by RIDC would be a highly beneficial development. It is recommended that key roles for the PRN as the cluster development organization should include:

- Coordinating the implementation of the strategies and actions outlined herein in collaboration with the major organizations that participated in and financed strategy development.
- Facilitating access to labs, prototyping, and testing infrastructure either through existing regional assets or through establishing new innovation hub facilities.
- Building consensus among key regional sector stakeholders in regard to the key "asks" of the state in terms of a multi-purpose, multi-user test and demonstration facility, autonomous systems business incubator, demonstration and testing corridors, and development of shared/contract manufacturing resources.
- Coordinating industry and investor networking.
- Providing shared business support and advocacy services in collaboration with the PTC.
- Developing entrepreneurial support activities (mentoring, accelerators, EIRs, etc.) in collaboration with IW.
- Coordinating social and promotional events (hackathons, industry awards, industry-sponsored competitions, etc.).
- Developing a branding/marketing initiative (Action 2.1) in collaboration with the PRA.

### Organizing for Success

The PRN is a marketing, trade association, branding, advocacy (to some extent) and networking organization, all of which is extremely important for successful cluster advancement. However, the need is to create a robust regional economic development initiative, that needs to include the research base, the talent pool, the regulatory environment, the attraction of companies, and the development of both regional jobs and the manufacturing supply chain that goes with that.

Accordingly, while PRN has made great strides and represents an important set of industry players, there is a need for a broader initiative. PRN may be able to grow into that entity but given the time sensitive nature of the opportunity (both need and funding availability) the report recommends using an established economic development entity to incubate the effort while the PRN gets built out.

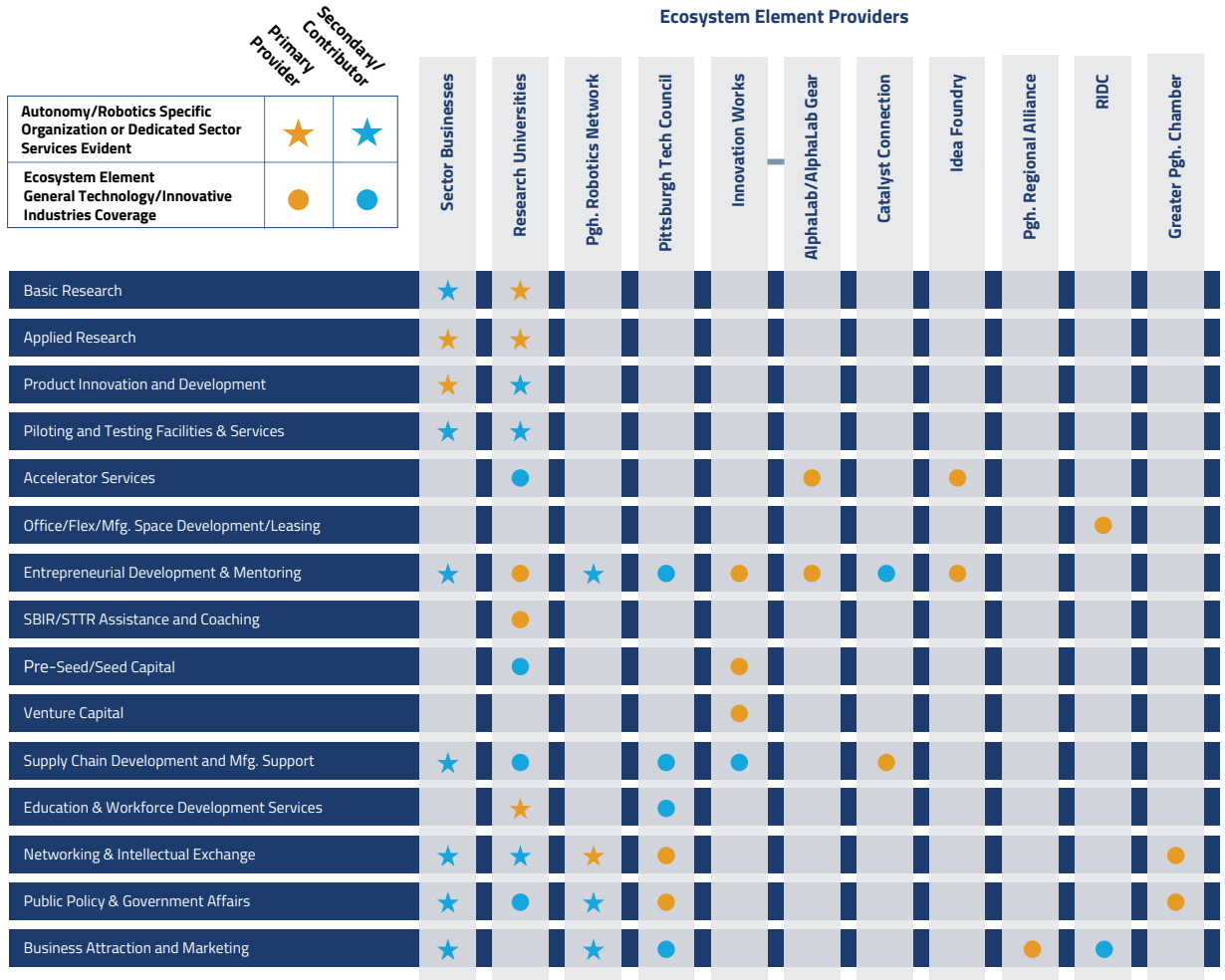
RIDC, with its regional footprint, diverse real estate portfolio, tenant base of Autonomy/Robotics companies, economic development experience, relationship to the academic, civic, state and industry players, and administrative capacity represents a desirable option for acting as the home for the initiative while the organizational infrastructure to host it long term is put in place.

Further conclusions relating to organizational structure and institutional participation in the autonomy and robotics opportunity for the region is highlighted further in this chapter and Figure 19.

The bottom line is simple—unless Pittsburgh's diverse base of economic development stakeholder organizations can be coordinated as a functional ecosystem, a critical mass of focused activity capable of advancing the autonomous systems industry will not be achieved. Coordinating and coalescing regional efforts behind a dedicated organization that can be the nexus for regional innovation and cluster development activity and collaborations in autonomous systems is critical to the further growth of this opportunity within the Pittsburgh Region.

RIDC, together with other key regional economic development entities impacting the innovation ecosystem generally (and the autonomy sector specifically), need to assist PRN in building a collaborative functional network with existing regional ecosystem stakeholders. No single organization in the region has the operational remit, nor the critical expertise, required to address the very wide range of ecosystem elements that must be paid attention to. Figure 18 illustrates this, showing many of the relevant regional ecosystem organizations and TEConomy's conclusions regarding their positioning in terms of supporting the further development or the autonomous mobile systems sector.

**FIGURE 18.**
## Stakeholders in Advancing the Ecosystem for Further Development of the Pittsburgh Autonomous Mobile Systems Sector



As the PRN evolves, it would play a central coordinating role for the autonomous mobile systems sector in terms of assuring services are supplied, and progress made, in each of the "ecosystem elements" shown on Figure 18 (the rows of the matrix). In effect, it is anticipated that PRN would work towards having an orange or green star in each of the rows (being a primary or secondary contributor to progress on each of those elements). This does not mean that PRN has to be the provider of the actual services that comprise each element (for example leasing business space, or providing venture capital), but it needs to be positioned to be working with the primary organizations in the region that address those elements to assure the autonomous mobile systems sector's needs are met. Other organizations need to embrace PRN as a key partner in their mission to advance the regional economy where it comes to autonomous systems and robotics. An organizational pathway towards realizing this 'institutionalization' of the strategy and action plan is discussed further in narrative surrounding Figure 19.

## Action 3.2: Address risk capital stack gaps

Regions with thriving innovation ecosystems share an important characteristic—they are home to a risk-capital community that is both oriented toward early-stage financing and committed to indigenous investment. Entrepreneurs require access to capital at each stage of their development, from early-stage, proof-of-concept and prototype development to Series A and B venture financing to debt financing. Regions that have a limited risk-capital stack in which to invest end up leaving their entrepreneurial companies on the "runway" unable to take off and reach their growth potential. Regions wishing to grow entrepreneurial companies have used a variety of mechanisms to encourage investment in risk capital and to address market gaps.

Ongoing trends in risk capital are making it even more imperative that regions have indigenous funds for the growth of innovative firms. These resident funds help in identifying promising innovations and technology advances, providing the initial funding to validate these opportunities, supporting the formation of new ventures, and providing the on-the-ground capacity to support these new ventures and facilitate their connection to later-stage venture capital and debt markets.

The cluster of companies in Pittsburgh in the autonomous systems industry is somewhat bifurcated in terms of experiences in accessing capital. The companies focused on autonomous vehicles sector have experienced an access to capital picture that is atypical for entrepreneurial ventures outside of the coasts – gaining quite rapid access to major venture capital and, moreover, large cash investments from partnering automotive OEMs seeking to position themselves with the companies demonstrating promising approaches, technologies, and experienced management. The experience of most other autonomous systems companies has been the more typical and challenging pathway of trying to access friends and family, angel investor, and early-stage pre-seed round funding to move them towards successful seed funding stages. SBIR and STTR funding have also been important given the R&D focused stage of development for many of the companies. Among the key capital issues to address include:

- A primary gap in rounds requiring between $1 million and $5 million in investment
- Series A and later also were noted to not be readily available from regional capital sources
- There is no dedicated pre-seed or seed fund focused on supporting the capital needs specific to the sector
- Achieving continuity in funding is critical due to typically expensive development cycles for autonomous systems products and the need to hit testing/deployment milestones to demonstrate value.

The region could address these funding gaps by:

- Developing a dedicated seed fund that has the ability to lead rounds and syndicate
- Developing a funding network that identifies and develops partnerships with investors outside the region for Series A rounds and beyond - capability could be incorporated as a role of the organization described in Action 3.1
- Coordinating major corporate investors that have already invested in the region – making the case that a shared funding pool to further grow the cluster is in their interests
- Better coordinating access to existing regional funding opportunities through the organization described in Action 3.1.

It has been well recognized among stakeholders within the region that Pittsburgh has had a shortage of locally-based venture capital funds that provide early stage investing. The positive news is that there have been recent announcements that indicate that new investment funds are being formed that will help to alleviate this shortage. Four have been announced since the Fall of 2020 — Magarac Venture Partners (MVP), Black Tech Nation Ventures (BTN), 412 Venture Fund LP, and The Fund Midwest. Two of the funds—412 Venture Fund and The Fund Midwest—have already reached first close, the halfway point where they can begin investing, although neither has done so yet. In addition, MVP and 412 Venture have indicated the intention to focus investments in artificial intelligence, robotics, and autonomous vehicles sectors, although they will not limit their investments to these sectors.

Having dedicated, locally managed, resident early-stage sources of funding is absolutely essential for helping to ensure that the burgeoning number of start-ups grow and scale in the Pittsburgh region. In addition, the presence of strong resident investment funds will be able to attract further outside regional and national funds to invest in Pittsburgh's growing pipeline of deal flow in the coming decade. It will be critical that the new funds be fully capitalized, particularly the two with investment models that include the autonomous systems industry, so that they are in the position to deploy capital quickly within the region to support the companies that are primed for significant growth with venture backing.

## Action 3.3: Enhance regional support mechanisms for autonomy industry entrepreneurs

Pittsburgh has a history of supporting innovative entrepreneurs, whether it be through partnerships with the state's Ben Franklin Partnership Program and its investments in Innovation Works, the federal government's investment in the Manufacturing Extension Partnership (MEP) through the targeted business development efforts of Catalyst Connection, or funding to support the network of Small Business Development Centers. While these efforts are significant and are drawing the attention of others from across the nation, there is considerable variance in the scope, scale, and efforts depending on the industry sector.

Consistent throughout discussions with leaders of this emerging industry is the perception that the regional support mechanisms for autonomy industry entrepreneurs fall short of the mark if Pittsburgh wants to use entrepreneurship as a way to build a more innovation-driven economy and leverage this significant opportunity. Interviews indicated that there is:

- A need for development of additional resources to support entrepreneurial experience in product development and market research – Pittsburgh currently has smaller knowledge base to draw on in autonomy commercialization than coastal competitors.
- An opportunity to support entrepreneurial development programs specifically targeted at the autonomous systems industry, ideally leveraging institutional excellence at CMU's Heinz College and Tepper and the Katz Graduate School of Business.
- A need to expand the scale and reach of programs such as Innovation Works' AI-Robotics Venture Fair that attracts tech investors that can serve the ecosystem.
- An opportunity to explore the need for additional feeder programs to better identify early-stage companies/university spin-outs that other regional autonomy companies can partner with/invest in.

It is proposed that these specific efforts be led by the organization described in Action 3.1 by working to coordinate Pittsburgh's existing regional support mechanisms to ensure a more intentional focus on the burgeoning autonomy industry entrepreneurs.

## **Strategy 4:** Further Develop the Regional Autonomous Industry Supply Chain

### Rationale

Currently, the autonomous mobile systems cluster in Pittsburgh is heavily focused on R&D. This is not unusual in a fast emerging technology sector, but if the sector remains solely focused (for the most part) on R&D and innovation alone the economic development opportunity will be constrained from reaching its full potential. While it is often assumed that the manufacturing of physical products (especially those with electronics components) is an offshore activity, the reality is that manufacturing is far from moribund in the U.S. and the types of components required to manufacturer the preponderance of autonomous mobile systems end-products may be sourced within the U.S., with a fair opportunity for sourcing within Pennsylvania and the Pittsburgh region.

It is currently relatively easy for companies to outsource their component manufacturing, and their final product assembly, to well-organized professional fabricators in the Far East. This may have advantages in terms of first costs, but there are hidden opportunity costs in offshoring and benefits can be derived from having closer relationships with domestic suppliers, especially local suppliers that can become strategic partners in product and process refinement and the fine-tuning of supply. There are also resiliency aspects to local supply chains that should not be discounted, some highlighted by risks to global supply chains exposed during the COVID-19 pandemic, but others associated with intellectual property security. Furthermore, the implementation of Manufacturing 4.0 technologies and processes is boosting U.S. manufacturing industry productivity, while reducing the labor-cost advantages for overseas locations via enabling domestic manufacturing automation.

In discussing manufacturing with those companies already engaged in it within the cluster in Pittsburgh, versus those that at present are not manufacturing, there was an observed dichotomy in plans and actions. The companies already manufacturing, or performing final assembly in Pittsburgh, (primarily, but not exclusively, serving warehousing and logistics market applications) are very much engaged in domestic sourcing and are able to point to commercial relationships with Pennsylvania-based suppliers of materials and components. That said, none of these companies are producing at the sort of volumes that are mass market (as would be experienced in the automotive sector), and there are several gaps in domestic and local component supply capabilities that

#### A Need for Domestic Supply Chains and Manufacturing

The volume of DOD funding directed to autonomous systems R&D is indicative of the strategic nature of the sector for our nation's national security. The strategic importance of the sector, however, runs far deeper because it is also key to the nation's future economic security (and it is the economy that ultimately underpins our national strength and global influence).

Autonomous systems are a pathway to significantly improved productivity across the economy and to the growth of a large advanced-industry base in the development, production, sales, and service of autonomous systems themselves. Realizing this full strategic potential, however, means that the U.S. must become a manufacturing center for key technologies in the autonomous systems stack, and invest in building a robust domestic supply chain. At the present time the U.S. has largely ceded manufacturing in industrial robotics to overseas manufacturers, but this need not and should not be allowed to happen in autonomous mobile systems.

Pittsburgh has secured major investments that have resulted in the formation of Carnegie Mellon's Manufacturing Futures Initiative (MFI) and the Advanced Robotics for Manufacturing (ARM) Institute – initiatives that are focused on transforming U.S. manufacturing via Industry 4.0 technologies (advanced robotics, artificial intelligence, materials science, additive manufacturing, etc.). As the federal government invests in our infrastructure and future (advancing major funding bills focused squarely on this), these and other assets position the Pittsburgh region favorably for major federal funding attraction. It will be particularly advantageous for Pittsburgh, in this regard, to apply its advanced manufacturing and supply chain development assets TOGETHER with a special focus on autonomous mobile systems as a fast-growth strategic industry, in order to maximally leverage current federal interests and attract large-scale federal funding.

were highlighted. Companies not yet manufacturing demonstrated a quite notable tendency to simply assume they would offshore that element of their business, but it appears their plans are far from firm.

**There are clear economic and societal benefits to be realized though building domestic supply chain connections for the autonomous mobile systems industry as it scales.** Just in terms of the diversity of jobs generated, pursuing domestic manufacturing production is high in its impact. Many of the autonomous systems companies in the region are led by scientists and technologists who do not have manufacturing experience and they need assistance to identify pathways forward that engage local supply chains and manufacturing opportunities. This is a key area in which the TBED ecosystem must be built-out to provide support and make it easy for companies to identify, access, and work-with domestic (ideally Pennsylvania and Pittsburgh regionally based) suppliers so that the full value-chain becomes built-out within the region.

## Action 4.1: Build out a contract manufacturing and regional supply chain consortium

Several autonomous mobile systems companies are already manufacturing components, sourcing components locally, or performing final assembly in the Pittsburgh region. Examples include Seegrid (logistics robots), Advanced Construction Robotics (rebar tying robots), and Carnegie Robotics (machine vision systems). These companies are proving that it is not necessary to offshore the majority of work to produce marketable manufactured products.

Under Action 4.1 it is recommended that the Pittsburgh Robotics Network, form a manufacturing sub-committee comprising leadership of companies in the autonomous mobile systems stack that are already engaged, or moving towards, manufacturing of their products. This subcommittee should also include membership from Innovation Works, Catalyst Connection, and ARM (organizations that have been active in considering manufacturing options for local technology enterprises). The new Manufacturing Futures Institute (MFI) at Carnegie Mellon will also be important to incorporate. The PRN and stakeholders should:

- Research and publish case studies of local autonomous systems companies that are successfully manufacturing in the U.S. and the region.
- Develop a database of regional and Pennsylvania-based companies with capabilities in meeting supply chain needs for autonomous systems components and finished products manufacturing. This list should be rounded-out with domestic companies outside of the state where necessary to identify full-stack component manufacturing capabilities.
- Leverage the networks of Innovation Works, Catalyst Connection and ARM to connect with manufacturing companies interested in serving the developing needs of the autonomous mobile systems industry.
- Identify gaps in the local supply chain that are deemed critical to fill to fully realize the manufacturing potential for the region and develop a strategy for recruitment of manufacturers or the development of new enterprises to fill the identified gaps.

The products that are developed for autonomous mobile system applications, even those addressing very different market verticals, have much in common in terms of the types of components and assemblies required. Common technology categories include:

- Sensors and sensing systems (including optical systems, lidar, accelerometers, etc.)
- Positioning/geo-spatial systems (e.g. GPS)
- Electronic and electrical control boards and circuitry
- Wireless communications technologies
- Electric motors and actuators
- Batteries and charging systems
- Housings (metal, plastic, composite)
- Wheels and braking systems
- Security and anti-tampering technologies
- Industrial coatings.

Identifying the components most likely to represent a shared need across multiple Pittsburgh-based autonomous mobile systems companies will provide a pathway to structuring a "high priorities" list for attracting contract manufacturers or for developing a contract manufacturing consortium among existing local manufacturing firms to meet anticipated demand. PRN should work with the Pittsburgh Regional Alliance to attract targeted manufacturers, such as Flextronics[18], to the region.

## Action 4.2: Identify shared, noncompetitive, technology areas for collaborative industry projects and attraction of supply base

In discussions with companies it was noted that there are certain shared component needs that still are not ideal in either their current supply situation or the current solutions available on the market. There are also components in which there would be industry advantages in standardized configurations and specifications being developed. These areas present an opportunity for development of pre-competitive or non-competitive partnerships or R&D consortia to be structured in the region, working with key university assets where feasible, to advance shared solutions.

Among the most common shared need/opportunity area raised by companies is batteries (and battery charging systems). It was noted that there would be advantages to be realized (particularly for customers that may require multiple autonomous system solutions) in terms of developing battery charging system standards and standard configurations.

In general, companies interviewed view their software systems and algorithms as their core intellectual property, whereas the physical components interfacing with the software are more likely to be considered less proprietary and more conducive to joint development projects.

The PRN should work with regional stakeholders to identify areas where shared R&D and innovation initiatives would be beneficial to advance standardized solutions to multiple-company needs. The production of standardized technologies could then be met through actions highlighted in 4.1.

18 https://flex.com/industries/automotive/autonomy

## **Strategy 5:** Create Demonstration and Testing Infrastructure Assets to Support Industry Scaling

### Rationale

Some industries can commercialize products and scale to market with minimal outside regulatory, safety, or public acceptance constraints. These tend to be industries that either have few safety risks or other externalities impacting the general public or do not require access to regulated public infrastructure. Large components of autonomous mobile systems industry are, however, impacted by both these factors. As companies move from ideation to prototypes that require intensive piloting and demonstration, they bump-up against the realities of having to navigate health and public safety regulations or the need to use shared, often public, infrastructure in order to demonstrate product viability and capabilities. This is an obvious reality for autonomous on-road cars and commercial trucks where testing in controlled or confined environments such as test tracks is only the first step to broader deployment. After initial testing the focus quickly moves to a need for operation in real world, on-road conditions in order to encounter a full range of operational environments, edge case events, and prove themselves by accumulating quality road mileage. Other autonomous mobile systems face similar demonstration challenges in either prototyping environments or realistic operating conditions in agricultural automation, construction automation, use of public airspace, warehousing and logistics environments, and indoor environments where public interactions may occur.

Having access to infrastructure for demonstration and testing is a critical industry need, with demand expected to increase in the future as systems move closer to market. Because R&D and product piloting and demonstration is often an interactive process, having test and demonstration facilities in, or proximate to, the City of Pittsburgh (where most of the autonomy companies are clustered) would clearly be advantageous. Beyond this, companies need facilitated access to public roads and infrastructure for testing and demonstration purposes with accommodating government stakeholders attuned to industry needs while also acknowledging the need to protect public safety and garner public support for deployment. There is also increasingly a need for having a regulatory pathway to full vehicular autonomous on-road operations in Pennsylvania as companies begin to make decisions about where the next phases of testing operations will be located. If large components of the industry are going to continue to grow in Pennsylvania, then the state needs to be on the leading edge of facilitating a world class testing and demonstration environment.

Embedding these shared testing, piloting, and demonstration assets within the Pittsburgh and broader Pennsylvania environment matters for industry growth, and strategic attention needs to be paid to developing specific environments in the public domain that are aligned to meet industry needs. It would also be beneficial for public agencies to be early adopters, and even a key customer base, of the products and services advanced by the autonomous mobile systems industry and to encourage their use in public contract services and public works.

### Action 5.1: Explore the potential for shared testing and demonstration projects that can serve as industry assets

While not all market applications of autonomous systems require large footprint demonstration and testing facilities, major components of Pittsburgh's current industry mix that are focused upon on-road vehicles do require early-stage testing facilities where they are able to accumulate operational mileage. Additionally, the region has an emerging cluster of companies focused on infrastructure, manufacturing, logistics, and urban air mobility that also have testing needs which are often conducted on-site with potential clients or leverage testing environments. Industry stakeholders have communicated that current large scale test facilities associated with autonomous vehicles (mainly focused on Pitt International Race Complex) are located some distance away from the business operations hub of "Robotics Alley". The exception is NREC, whose 1 and 2-acre on-site testing grounds are suitable for small and mid-scale robotics systems, but this resource does not have the size or capacity for large autonomous systems to accumulate ongoing operational data. Additional testing of other types of autonomous systems is conducted internally within company facilities, potentially leading to duplicative company investments

in infrastructure (or barriers to entry for emerging firms) and limiting exposure and awareness of the significant advancements being made within the region.

The current environment presents an opportunity to aggregate testing and demonstration activity at signature, shared-use sites that have proximity to the urban core of the region and could allow for seamless transitions between the testing environment and public demonstration within the urban roadway network and built environment of the city. Stakeholders communicated that such a facility would be attractive in testing operations location decisions and could function as industry attraction asset for economic development agencies.

The region should convene industry planning groups to discuss industry needs and identify potential sites for testing and demonstration hubs spanning a set of autonomous systems applications and develop funding proposals in conjunction with the actions outlined in Strategies 1 and 2. Several key project needs identified by regional stakeholders have included:

- A test track "proving grounds" facility designed to provide early-stage validation, use case data gathering, and extended demonstration time functions for autonomous vehicles platforms. Such a facility would ideally be located within the urban core of the city and sited to allow direct transitions between public roadway environments and the test track to conduct real world validation and demonstration. Stakeholders have cited the need for the facility to be administered by a "neutral" 3rd party entity with access provided for both established and emerging companies. Examples of signature facilities other states have created that can serve as a potential blueprint for creation of a signature autonomous mobile systems testing facility and the associated services and collaboration models include:

    - DriveOhio's Smart Mobility Advanced Research Center (SMART Center), funded by a commitment of $45 million from ODOT and JobsOhio. The center will be an automated and connected vehicle-testing facility to be built on 540 acres of the current grounds of the long-standing Transportation Research Center (TRC). The TRC is a state-chartered not-for-profit that bills itself as the largest independent vehicle test facility and proving grounds in the nation, and contracts for management and research services with The Ohio State University. This partnership is continuing to leverage state investments with new federal grants, such as a recent award of $7.5 million toward a $17.8 million state DOT project to bring advanced technologies to Ohio's rural highways.

    - Mcity's Test Facility (in Michigan), created in 2014 and combined with an industry-sponsored research program, all housed at the University of Michigan with a cumulative total of $26.5 million invested since 2015 in research, development and deployment projects. The facility is a 32-acre artificial urban/suburban setting equipped with 5G vehicle-to-everything service, supplemented by advanced digital control and monitoring services. The entire facility is managed by a cloud-based open-source operating system giving users point-and-click control over interactions between vehicle and facility features and infrastructure, and this software is in turn licensed by other testing facilities. The facility has numerous university, state government, and industry partners (including most major automakers and several AV companies) who leverage the facility for applied research, regulatory and policy development, and demonstration projects.

- Establishing an urban air mobility testing corridor within the built urban environment to attract additional companies to the region seeking to demonstrate and support the emerging companies focused on this end market. Infrastructure and regulatory support required to obtain special flight testing approval would help advance applications in this market segment and could be coordinated through an entity such as the Mid-Atlantic Aviation Partnership (MAAP) that provides certification and testing capabilities to demonstration sites. A UAS demonstration corridor would be especially beneficial to the region in attracting industry and research partners if there was support for obtaining flight testing approval

from the FAA for special authorizations for cargo transportation and deliveries (which constitutes a more near-term application area for urban air mobility use cases than passenger air vehicles).

- Using the Platform Pittsburgh Smart City Research Testbed assets (which are primarily deployed around CMU's campus in Oakland) as well as the Pittsburgh Smart Spines Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) grant, the region should seek to actively build out additional sensors and capacity to advance the ability to advertise as one of the largest connected test bed and monitoring environments in the nation. This buildout should include expansion of new sensing and connectivity capacity, but also better coordination of the significant levels of existing infrastructure to compete for additional federal funding and aggregate available resources into a cohesive testing and demonstration asset that can be leveraged by both researchers and industry partners. As a part of this buildout, the region also needs to expand other shared "smart city" infrastructure such as 5G network coverage and dedicated short range communications technology (DSRC) spectrums for autonomous systems to leverage. Major opportunities exist for the region in coordinating a unified "point of access" for existing and new camera, sensing, and communications infrastructure as well as the creation of pooled administration and data management infrastructure that can begin to unlock the potential for the city to become a broader test bed for emerging technologies in this space.

## Action 5.2: Implement a set of ongoing, public-facing autonomous systems demonstration projects

Public acceptance of autonomous systems is seen as a critical factor in driving eventual adoption and market scalability of the technology, particularly for autonomous vehicles. Recognizing that public opinion and perception of autonomous systems represents a key constraint to widespread deployment, the region should undertake a set of high-profile demonstration projects that highlight the region's innovative capabilities, assist in branding and marketing efforts, and seek to drive public awareness and receptivity to various autonomous systems platform applications.

Public demonstration projects could be funded through public-private partnerships leveraging funding sources developed as a part of the actions involved in Strategies 1 and 2, and should involve coordination between regional civic stakeholders, university researchers, and industry sponsors to identify successful use cases for projects beyond the footprint of current industry testing efforts. Potential demonstration projects that could be implemented throughout the region in highly visible public environments include:

- Geofenced autonomous vehicle routes that serve major regional transportation arteries, for example the creation of an airport to downtown corridor or utilizing the busway rapid transit (BRT) protected lanes to create a structured operating environment for autonomous passenger vehicles.
- Major construction and infrastructure renewal projects that leverage mobile robotic systems, for example leveraging Advanced Construction Robotics' bridge construction robots in conjunction with a "live cam" documenting operations or other promotional efforts.
- Deployment of autonomous systems designed by local industry sponsors for sanitation and other public utilities applications in key commerce and entertainment districts within the city.
- Location of an urban air corridor for cargo transportation (as described above in action 5.1) at a highly visible river crossing space where UAS traffic could be safely observed by the public.

While many of these projects would realize some benefits in operational efficiency for the city, their primary purpose would be to showcase technologies for the public and serve as marketing assets for use in conjunction with Strategy 2. Demonstration project rights could also serve as a source of publicity for city by awarding them to companies seeking to advertise their systems in a competitive process similar to the model used by the DARPA Grand Challenge autonomous vehicle competitions.

The region should also explore opportunities to embed autonomous systems into public transportation and other urban infrastructure through similar processes as a means of addressing urban mobility issues and providing transit access to underserved areas and populations within the city and region. Autonomy and other smart city technologies are seen as critical to improving access and reliability of public transit and safety for underserved communities in a cost-effective manner for cities, and leaders in integrating autonomy into civic operations are likely to see dividends in both reduced overhead costs as well as operational efficiency. In turn, successfully embedding emerging technologies into public infrastructure is likely to drive increased business and talent attraction as a placemaking effect.

## **Strategy 6:** Expand the Talent Pipeline to Support Growth of the Autonomous Systems Industry

### Rationale

It is maybe somewhat ironic that the autonomous systems sector is highly dependent on skilled human capital for its development. However, as a science- and technology-based R&D and industry sector, it is absolutely driven by highly educated and skilled personnel. Indeed, Pittsburgh's signature capabilities in higher education across relevant disciplines is the reason the industry is present and growing in the region. In large-part, the long-standing academic excellence of Carnegie Mellon University in robotics, associated engineering disciplines, and in computer science is the seed from which the industry has grown. Carnegie Mellon, and the affiliated National Robotics Engineering Center (NREC), have educated or employed (as faculty) many of the founders of pioneering robotics and autonomy companies in the region. Other regional higher education institutions, such as the University of Pittsburgh, have also contributed to the talent ecosystem and are likely to play an increasingly important role in meeting expanding talent demands as the industry scales.

Carnegie Mellon University's world-leader profile in both research and higher education across the disciplines central to autonomous systems advancement is an essential element in the case for the sector as a key strategic industry driving future regional and state economic fortunes. It must be recognized, however, that Carnegie Mellon will not be able to scale to meet the full talent demands of the autonomy sector as it continues to grow. Trying to do so would skew the University too much in one direction academically, and the campus is quite constrained in terms of its physical ability to expand its footprint. Carnegie Mellon has demonstrated significant commitment to ongoing growth in relevant fields, and recent major projects (including the recent RK Mellon Foundation funded award to the University) demonstrate that further growth will occur. The reality is, however, that the output of graduates from Carnegie Mellon will not be sufficient to meet the scaling needs of the industry. Because of these constraints, and because the autonomy industry will be evolving into broader business functions (up to and including manufacturing), the talent demands require that other regional higher education institutions be proactively engaged. Multiple regional higher education institutions have programs in engineering, computer science, and associated disciplines of direct relevance to the expanding needs of the industry cluster, and their engagement in meeting the needs of the cluster will need to be encouraged and coordinated. As the industry scales, job opportunities will exist from entry level positions in support, warehousing, and manufacturing operations through to the highly trained PhD robotics and computer science graduates. The region needs to highlight and facilitate pathways to the education required for the diversity of job opportunities the industry will provide.

The workforce demand and qualifications for talent in the autonomous mobile systems space is explored further in Appendix F.

### Action 6.1: Expand the talent pipeline through coordination across regional institutions

As previously noted, Carnegie Mellon University is a world-leader in the disciplines central to autonomous systems advancement, and as such, is critical to producing the talent that will anchor the growth of the industry in the region. However, Carnegie Mellon does not have the capacity to fill all the talent demanded by the region's autonomy sector as it continues to scale. Instead, the anticipated talent demands require that other regional higher education institutions be proactively engaged.

Undergraduate and graduate students pursuing degrees in related fields do not know enough about this emerging sector and the opportunities it affords in the region. It will be critical to **create career awareness programs** at regional schools that are focused on educating students about opportunities within the sector and ultimately retaining graduates with relevant degrees. By advancing academic program engagement with the autonomous systems industry, curriculum will be able to be shaped and applied learning opportunities (e.g., capstone projects, case studies) will be able to be developed at regional schools outside of Carnegie Mellon. This could potentially include joint degree/certification programs in autonomy-related specializations, joint faculty appointments, and other mechanisms to increase collaborative circulation of best practices and build collective talent pools that are aligned with industry.

**One way to do this is by providing professional development opportunities for faculty/staff within engineering, IT, computer science, business, and other autonomous-related degree programs.** Faculty and staff can share in their classrooms only knowledge that they themselves have garnered. Curriculum development and modification are largely the prerogative of the faculty. Yet, there is little investment in professional development for faculty to learn about the demands of the autonomous systems workplace and to be involved in externships around industry functions relating to their fields. It is suggested that faculty be able to apply for professional development sabbaticals and summer externships with autonomous systems companies during which they can develop case studies, course materials, and student career development programs. **It will be as important to raise awareness of the autonomous systems opportunity at local technical colleges and vocational schools as it is with four-year institutions.** Associate level and certification programs will also need to collaborate with industry to build programs that can supply supervised autonomy operators, skilled fabricator and assembly workers, maintenance workers, and other middle skills occupations that can serve the growing industry. The organization evolving as part of Action 3.1 could oversee the development and placement of these career development opportunities.

**Once faculty have availed themselves of these professional development opportunities, they will be able to integrate autonomous system-related curriculum and case studies into relevant degree programs.** Autonomous systems provide numerous compelling real-world examples that can be brought into the classroom and used to enhance student learning, providing opportunities for students to practice their skills within an autonomous system-related context. Problems taken from, or at least based on, actual industrial experiences provide context and relevance to students. These types of cases and problems also provide opportunities for students to learn by doing. They may even be able to contribute to solutions to the real-world problems that they are given. However, at the moment, very few case studies and problem-based learning assignments within engineering, business, IT, and other related degree fields have any relevancy to the autonomous industry. This lack of exposure to the sector limits students' understanding and interest in the field. It is recommended that a series of case studies and problem-based learning exercises be developed for curriculum within related occupation degree fields and integrated into the curriculum. The organization created as part of Action 3.1 could oversee programs being piloted at a select number of institutions and once developed, could be expanded to all higher education institutions across the region.

**Another avenue to explore is creating business case study competitions at the MBA level and Senior Capstone projects at the Undergraduate Level** – working to provide opportunities to reach graduate and undergraduate students and expose them to an in-depth look at the autonomous systems industry sector. In terms of an MBA business case study competition, events typically bring together dozens or even hundreds of very bright, connected people, and highly engaged company representatives on the lookout for new talent. While the focus and formats of case competitions can vary quite widely, they all share a dual purpose: (1) to advance students' business skills and (2) to help students build connections that will aid in their career development through interacting with peers from other schools and networking with representatives from sponsoring companies who often use their participation for recruiting. While a senior capstone project is typically more internally facing than an MBA business case competition, the opportunity to explore a component of the autonomous systems industry still exists. It is also possible to develop relationships with at least a few companies through the course of the project. Again, the

organization created as part of Action 3.1 could oversee the development of pilot programs, and once developed, could expand these efforts to higher education institutions across the Pittsburgh region.

**Finally, once students are interested and engaged, meaningful experiential learning opportunities should be created that connect them with industry, thereby helping to ensure that talent is retained in the region.** Within professional degree programs, there is a long tradition of including field experiences as a way to build practitioner skills and facilitate the move from theory to practice. Two of the most common forms of workplace learning are cooperative education (co-op programs) and internships. In co-op programs, students will alternate periods of paid work with campus study or split their time between the workplace and the campus. An internship provides students with relevant work experience over a shorter, set period of time.

Both co-op programs and internships are structured and supervised experiential learning opportunities that provide students with practical experience in their chosen fields. Co-op programs and internships illustrate classroom relevance in the professional world. Beneficial for both students and employers, they offer career exploration and skills application opportunities for students and provide employers with workers who are creative, enthusiastic, are able to assist with projects, and are open for mentorship. Transitioning students into full-time employees is also a proven time- and cost-saving recruiting method.

Experiential education can help students gain the following:

- a deeper understanding of subject matter than is possible through classroom study alone;
- the capacity for critical thinking and application of knowledge in complex or ambiguous situations; and
- the ability to engage in lifelong learning, including learning in the workplace.

To further ensure the retention of students in the region, different funding incentive models should be explored to retain new graduates in well-aligned engineering and computer science categories. Incentives could include "signing bonus" awards, loan forgiveness, and other state and local tax incentives.

The hardest part of developing co-op programs and internships is gaining the participation of employers. The Pittsburgh region needs a coordinated outreach effort and consistent platform across higher education institutions granting autonomous systems related-degrees to stimulate and implement employer involvement with co-op programs, internships, job shadowing, and other work experience activities for students. The organization created as part of Action 3.1 could oversee the internship and co-op coordination efforts between industry and higher education as well as explore and implement retention incentive models.

## Action 6.2: Address current gaps in the region's autonomy industry talent base

Regional stakeholders have noted several key gaps in the autonomous systems industry's current talent mix:

- Lack of a broad base of experienced technology entrepreneurial executive talent (C-suite talent) that can help scale companies.
- Shortage of product sales/marketing, customer experience, and UX/UI talent embedded within autonomous systems companies.
- Difficulties in finding embedded software and systems software engineers that are more specific to robotics and autonomy space.
- High demand and high intra-regional wage competition for mid/senior level tech talent (graduate degree and/or significant tech company experience levels) is leading to pressures on small and mid-sized autonomous systems companies.
- An anticipated need for an expanded supply of robotics technicians and a workforce trained in the maintenance of autonomous systems.

What these stated needs make clear is that simply having a diploma in hand does not mean that the pursuit of knowledge can come to an end. Autonomous systems professionals require access to educational offerings and specialized training that continue to expand their knowledge and introduce them to new areas of inquiry and skill sets. The need to develop certification programs to meet industry needs in emerging and high-demand areas is critical. Making these certification and other forms of advanced training accessible to the extremely busy career professional is critical to Pittsburgh's success in

staying on the cutting edge of autonomous systems innovation. Even formal graduate education courses, need to meet the needs of professionals seeking to advance their careers by offering evening, weekend, and online course instruction.

The region should work with Carnegie Mellon, the University of Pittsburgh, and other regional institutions (especially those with robust engineering and computer science programs) to develop postsecondary certification, accelerated applied graduate degrees, and continuing education programs in areas of key technical demand identified by industry to help backfill talent needs at small and mid-size companies. **In this latter regard, it will also be critically important to engage the region's community colleges and technical career-oriented training institutions in addition to the universities.** As the industry advances its innovations into tangible products, workforce demands will expand to incorporate manufacturing oriented jobs (as has already occurred at a few companies, such as Seegrid). The organization created as part of Action 3.1 will need to work with industry to determine emerging skill sets that will be required for professional career advancement in both technical and managerial functions, and for emerging manufacturing positions, then work with academic institutions to develop specific programs to deliver this specialized training to ensure the necessary skill sets can be easily accessed in Pittsburgh.

In addition, as careers advance, the need for networking does not diminish, but in fact can become even more important. In conjunction with the organization outlined in Action 3.1, it will be critical to expand the regional robotics CEO group to include executive training and mentoring program functions for aspiring entrepreneurs in order to more broadly diffuse business experience across the industry. It will also be important to identify and groom executive tech leadership aligned with the autonomous systems industry as a part of Action 6.3.

## Action 6.3: Expand initiatives to attract new talent to the industry from outside the region

As the local autonomous systems industry continues to grow, there will be an ongoing need to attract high quality talent to the region to boost entrepreneurial activity and support the expansion of scaling companies. As such, the region should incorporate autonomous systems talent attraction into its regional workforce development programs as a key target to help grow the sector.

While growing talent from within will always be the best approach to sustaining a strong regional economy, there are opportunities to attract talent from elsewhere. Pittsburgh's significant and recognized position within autonomous systems means that as costs become untenable in regions like Silicon Valley or Boston, there are opportunities to attract migrating talent from these places.

A survey recently found that 85 percent of adults would describe themselves as willing to relocate, but that economic factors play the largest role in determining their relocation.[19] Starting a new job or career to improve salaries is the primary reason respondents would consider relocation (24 percent), while starting a new job with new/more benefits was ranked second (19 percent)[20]. Housing costs, cost of living, and housing availability rank among the top location factors considered during relocation.

Ultimately, economics will be the reason why individuals choose to locate to the Pittsburgh Region: relocation decisions are made based on an opportunity to improve relative economic conditions, and where the risks associated with relocation (e.g., high housing costs, lack of social networks) are relatively low. This holds true for lower-skilled and higher-skilled workers alike. Innovative firms want to be in areas where they can improve their business performance with relatively few risks, so they go to places with a deep pipeline of relevant talent and an attractive quality of life. Likewise, skilled workers increasingly want to live in areas where other skilled workers live, where jobs are plentiful, and where networks and amenities are accessible.

19 Development Counsellors International (DCI), "Talent Wars: What People Look for in Jobs and Locations," Q2 2019.
20 Ashutosh Dixit, Candice Clouse, and Nazli Turken, Cleveland State University Economists, "Strategic Business Location Decisions: Importance of Economic Factors and Place Image," Rutgers Business Review Vol. 4, No. 1, Spring 2019.

However, the ability for individual companies, particularly small companies, to attract talent is difficult and costly. According to recent research by McKinsey, 82 percent of companies do not believe they recruit highly talented people. For companies that do, only 7 percent think they can keep them. More alarmingly, only 23 percent of managers and senior executives active on talent-related topics believe their current acquisition and retention strategies work.[21]

With this in mind, the Pittsburgh region should collaboratively implement initiatives focused on attracting talent to the region to help the entire autonomous systems industry, instead of individual companies feeling like the burden rests solely on them. The organization created as part of Action 3.1 should be tasked with implementing a talent attraction campaign that focuses on coordinating the efforts of various entities from across the region to focus a targeted message to autonomous systems talent. Serving as a "portal" of information, the attraction campaign could include:

- A dynamic web portal that not only can serve as a clearinghouse for job opportunities within the region but can also showcase the region's strengths in the industry overall as well as highlight Pittsburgh's quality of life/place leveraging the region's cost of living and housing availability advantages relative to coastal competitors.
- A talent attraction "training camp" event for local talent acquisition agencies to better inform professionals in the field of all that Pittsburgh has to offer.
- Collaborate with leading academic institutions in Pennsylvania, Ohio, West Virginia, and Michigan to develop increased talent flow to the Pittsburgh region. Many of the ideas discussed under Action 6.1 could be, over time, expanded to nearby Tier 1 Research Universities, with a particular focus on recruiting students for internships and co-ops.
- Expand "re-attraction" programs targeting alumni from local institutions who have a connection to the region and may be more receptive to relocation.

## Timing and Prioritization of Actions

Recognizing that not all actions can be undertaken immediately, Table 5 identifies two classifications for each strategy and its subsequent actions:

- The classification of **priority**: (1) Critical applies to those actions that are essential for the success of the strategy, (2) Significant to those actions that can make a major impact in advancing the strategy, and (3) Important to those actions that can contribute to the success of the strategy.
- The classification of **timing**: Short-term actions should be undertaken in the first 6 months; mid-term actions should be undertaken in the 6 month to 24 month period; and long-term actions may be implemented on a longer multi-year time horizon.

21 See: https://www.mckinsey.com/business-functions/organization/our-insights/attracting-and-retaining-the-right-talent#

**TABLE 5.**

## The Pittsburgh Region's Autonomous Mobile Systems Strategy – Implementation Timetable

| Strategy 1: Strategy 1: Advance a State Level Autonomy Program to Position the Region for Future Growth | | |
|---|---|---|
| **ACTION** | **PRIORITY** | **TIMING** |
| **Action 1.1:** Develop and advance a framework for a signature state initiative in autonomy | (1) Critical | Mid-Term for implementation but planning should begin immediately |
| **Action 1.2:** Take a proactive stance in developing forward-thinking regulatory guidance for policymakers | (1) Critical | Short-term. Will take time to develop, so needs to be started quickly. |

| Strategy 2: Advance the Identity of the Region as a Leading Autonomous Systems Hub Serving a Diverse Set of Markets | | |
|---|---|---|
| **ACTION** | **PRIORITY** | **TIMING** |
| **Action 2.1:** Develop a branding and marketing initiative that can increase both external and internal public awareness | (2) Significant | Short-term |
| **Action 2.2:** Develop a business attraction initiative targeting scaling and mid-size companies in the technology stack | (2) Significant | Mid-Term |
| **Action 2.3:** Attract leading trade shows, conferences, and other high-profile showcase events | (3) Important | Long-term. It will take time to build interest and secure events that are usually planned significantly in advance. |

| Strategy 3: Coordinate the Region's Innovation Ecosystem Assets to Support the Autonomous Systems Industry | | |
|---|---|---|
| **ACTION** | **PRIORITY** | **TIMING** |
| **Action 3.1:** Support a dedicated organization that can be the nexus for regional innovation and cluster development activity in autonomous systems | (1) Critical | Short-term. Convene significant support for PRN as core cluster organization, and secure partnerships with ecosystem organizations. |
| **Action 3.2:** Address risk capital stack gaps | (2) Significant | Mid-term |
| **Action 3.3:** Enhance regional support mechanisms for autonomy industry entrepreneurs | (3) Important | Mid-term |

| Strategy 4: Further Develop the Regional Autonomous Industry Supply Chain | | |
|---|---|---|
| **ACTION** | **PRIORITY** | **TIMING** |
| **Action 4.1:** Build out a contract manufacturing and regional supply chain consortium | (2) Significant | Mid-term |
| **Action 4.2:** Identify shared, noncompetitive, technology areas for collaborative industry projects and attraction of supply base | (2) Significant | Mid-term |

| Strategy 5: Create Demonstration and Testing Infrastructure Assets to Support Industry Scaling | | |
|---|---|---|
| **ACTION** | **PRIORITY** | **TIMING** |
| **Action 5.1:** Explore the potential for shared testing infrastructure projects | (1) Critical | Short-term |
| **Action 5.2:** Implement a set of ongoing high-profile demonstration projects | (1) Critical | Mid-term |

| Strategy 6: Expand the Talent Pipeline to Support Growth of the Autonomous Systems Industry | | |
|---|---|---|
| **ACTION** | **PRIORITY** | **TIMING** |
| **Action 6.1:** Expand the talent pipeline through coordination across regional institutions | (1) Critical | Mid-Term |
| **Action 6.2:** Address current gaps in the region's autonomy industry talent base | (2) Significant | Mid-term |
| **Action 6.3:** Expand initiatives to attract new talent to the industry from outside the region | (2) Significant | Mid-term |

# Organization for Strategy Implementation

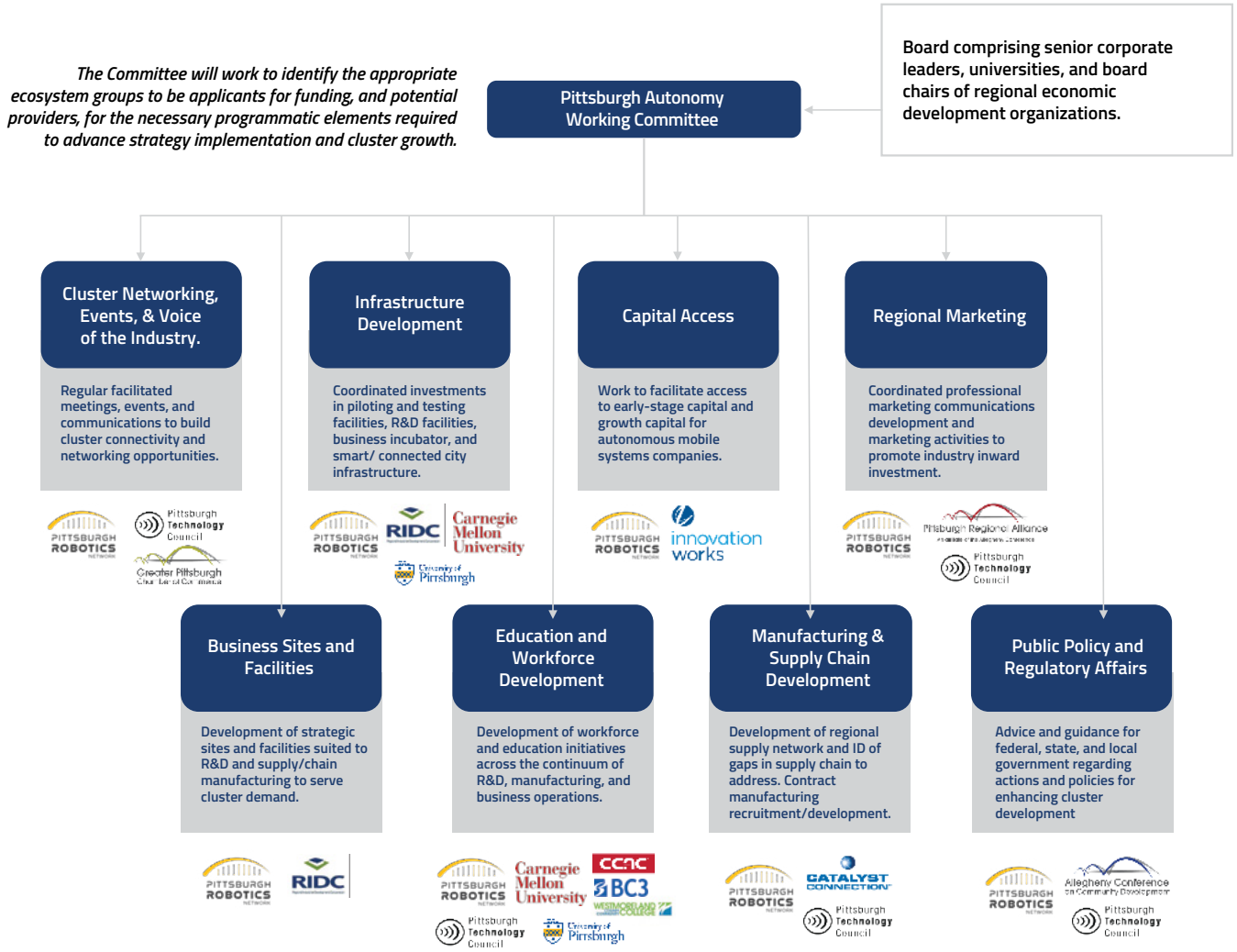
As noted previously (and highlighted on Figure 18), the Pittsburgh region benefits from having a broad range of experienced economic development-focused organizations that provide quite robust coverage of key innovation- and technology-based economic development services. Some of these services are specific, or have elements tailored to, the robotics and autonomous systems sectors, while others are more cross-cutting, available to service companies in most innovation sectors. The one organization that is 100% focused on the robotics and autonomous systems space is the Pittsburgh Robotics Network (PRN), which is the industry-led organization representing the sector.

Advancing the full strategic plan outlined herein will require significant oversight, since implementation will require the management and allocation of large-scale funds. With substantial funding likely to be sought from public entities, including the Commonwealth of Pennsylvania and the U.S. Federal Government (through EDA, DOT programs, etc.), together with philanthropic donations, there is a need to establish an oversight organization with the appropriate IRS designation and fiduciary protections. As a placeholder name for the proposed organization, this document uses the "Pittsburgh Autonomy Working Committee" as a temporary descriptor.

As envisioned the Working Committee will comprise a high level board including Presidents or CEO's of regional autonomous mobile systems companies, leadership of research universities, and the board chairs of primary ecosystem non-profit TBED organizations. The Working Committee would be responsible for supervising the implementation of the strategy and will seek proposals from ecosystem organizations to provide services in key functional aspects of strategy and action implementation. Figure 19 shows this conceptual structure, the key categories of ecosystem functions needing to be addressed, and key examples of organizations that would be likely recipients of funding to deliver the necessary programming/programs.

**FIGURE 19.**

## Potential Leadership for Strategy Implementation and Ecosystem Organizations to Engage



# Estimated Budget for Strategy Implementation

As noted in the impact analysis section, the likely economic benefits of realizing the full potential of the autonomous mobile systems as an industry cluster for the Pittsburgh region and the Commonwealth of Pennsylvania are extremely large. Already the industry in the region (which is primarily, but not exclusively, R&D focused at the present time) supports ~6,300 direct jobs with >$650 million in annual employment compensation and a direct economic output of approximately $1.5 billion. When indirect and induced impacts are accounted for, the overall current impact rises to circa 15,000 jobs, supporting employment compensation of over $1.2 billion, and sustaining a total economic output of approximately $3 billion. As the industry scales into full-production of commercial products and services, the upside economic impact opportunity will be much larger still. As noted in the Introduction chapter, autonomous mobile systems will represent a fast emerging $1 trillion global industry opportunity by 2025/26, and Pittsburgh's robust core competencies positions it well to be a major participant in this transformational economic opportunity. Realizing this full potential, however, requires addressing some of the shortfalls and gaps in the regional ecosystem, coordinating strategies and actions designed to optimize the regional autonomy environment and supporting ecosystem for competitive success. Addressing these needs requires investment of both dollars and human capital across the multiple strategies and actions outlined herein.

To place some bounds around the likely level of investments needed, an initial budget estimation has been prepared covering each of the strategies and actions (Table 6). In total, it is estimated that full strategy and action plan implementation will require approximately $154 million, with the Commonwealth of Pennsylvania funding 36.4% ($56 million), the Federal Government 13% ($20 million), and regional or local resources funding 50.6% ($78 million).

The current federal administration and congress are appropriating high levels of funding to federal agencies tasked with supporting major infrastructure and economic development programs. There is also significant attention being paid by the administration to supporting the development of regional specialized advanced industry clusters in regional hubs outside of the typical coastal concentrations. The timing for the Pittsburgh region in having a strategy ready to launch around autonomous mobile systems is serendipitous – coinciding with large-scale potential government funding support for such initiatives. The opportunity may be there for the region to secure more funding for the strategy implementation from federal sources than are highlighted in Table 6, thereby requiring relatively less from local/regional or Commonwealth sources.

**TABLE 6.**

## Preliminary Budget Estimation for Full-Scope of Recommended Strategies and Actions.

| Strategies | Actions | Action Element | Commonwealth Funding | Federal Funding | Regional Funding | Notes |
|---|---|---|---|---|---|---|
| **Strategy 1: Advance a State Level Autonomy Program to Position the Region for Future Growth** | | | | | | |
| | **Action 1.1:** Develop and advance a framework for a signature state initiative in autonomy | | | | | Some regional /local funding may be able to take the form of in-kind contributions for federal or commonwealth matches. |
| | *Action 1.1 element* | *Multi-purpose, multi-user test and demonstration facility for autonomous mobile systems* | $25,000,000 | $10,000,000 | $15,000,000 | |
| | *Action 1.1 element* | *Robotics business incubator facility* | $5,000,000 | $2,500,000 | $2,500,000 | |
| | *Action 1.1 element* | *Establishment of geofenced demonstration corridors* | $2,000,000 | | $1,000,000 | |
| | *Action 1.1 element* | *Provide initial funding for attracting, or developing, a contract manufacturing center and manufacturing network in the Pittsburgh region* | $250,000 | | $250,000 | Use of regional incentives for business attraction, and funding for network formation and operation |
| | *Action 1.1 element* | *Develop and fast-track a clear pathway for full autonomous transportation deployment that is competitive with other states that are already allowing fully autonomous testing on state and municipal roads* | Time only | Time only | Time only | |
| | *Action 1.1 element* | *Provide an operational funding support grant to the Pittsburgh Robotics Network to support its further development and growth* | $1,000,000 | | $1,000,000 | Also covers Action 3.1 |
| | *Action 1.1 element* | *PennDOT and the Pennsylvania Turnpike should commit to being early adopters of autonomous solutions for construction projects, roadway maintenance, and smart traffic management.* | $15,000,000 (Increased state project costs, but with goal of advancing industry and leading to savings over time). | | | |

| Strategies | Actions | Action Element | Commonwealth Funding | Federal Funding | Regional Funding | Notes |
|---|---|---|---|---|---|---|
| | **Action 1.2:** Take a proactive stance in developing forward-thinking regulatory guidance for policymakers | | Time only | Time only | Time only | |
| | **Action 1.3:** Advance public-private smart infrastructure projects that support autonomous systems deployment | | $5,000,000 | $5,000,000 | $5,000,000 | |
| | | | **$53,250,000** | **$17,500,000** | **$24,750,000** | **Strategy 1 Total** |
| **Strategy 2: Advance the Identity of the Region as a Leading Autonomous Systems Hub Serving a Diverse Set of Markets** | | | | | | |
| | **Action 2.1**: Develop a branding and marketing initiative that can increase both external and internal public awareness | | | | $500,000 | |
| | **Action 2.2:** Develop a business attraction initiative targeting scaling and mid-size companies in the technology stack | | | | $250,000 | |
| | **Action 2.3:** Attract leading trade shows, conferences, and other high-profile showcase events | | | | $50,000 | |
| | | | **$0** | **$0** | **$800,000** | **Strategy 2 Total** |
| **Strategy 3: Coordinate the Region's Innovation Ecosystem Assets to Support the Autonomous Systems Industry** | | | | | | |
| | **Action 3.1:** Support a dedicated organization that can be the nexus for regional innovation and cluster development activity in autonomous systems | | Covered under 1.1 | Covered under 1.1 | Covered under 1.1 | See Action 1.1 |
| | **Action 3.2:** Address risk capital stack gaps | | | | $50,000,000 | Raising a regional venture fund, with goal of $2-5 million investments |
| | **Action 3.3:** Enhance regional support mechanisms for autonomy industry entrepreneurs | | | | $250,000 | Grants to existing ecosystem organizations to cover |
| | | | **$0** | **$0** | **$50,250,000** | **Strategy 3 Total** |

| Strategies | Actions | Action Element | Commonwealth Funding | Federal Funding | Regional Funding | Notes |
|---|---|---|---|---|---|---|
| **Strategy 4: Further Develop the Regional Autonomous Industry Supply Chain** | | | | | | |
| | **Action 4.1:** Build out a contract manufacturing and regional supply chain consortium | | $1,000,000 | $1,000,000 | $500,000 | PTC and PRN with Catalyst Connection |
| | **Action 4.2:** Identify shared, noncompetitive, technology areas for collaborative industry projects and attraction of supply base | | Time only | Time only | Time only | PRN |
| | | | **$1,000,000** | **$1,000,000** | **$500,000** | **Strategy 4 Total** |
| **Strategy 5: Create Demonstration and Testing Infrastructure Assets to Support Industry Scaling** | | | | | | |
| | **Action 5.1:** Explore the potential for shared testing and demonstration projects that can serve as industry assets | | Covered under 1.1 | Covered under 1.1 | Covered under 1.1 | |
| | **Action 5.2:** Implement a set of ongoing, public-facing autonomous systems demonstration projects | | $1,000,000 | $1,000,000 | $1,000,000 | $1 million grants to support initiation of 3 signature projects |
| | | | $1,000,000 | $1,000,000 | $1,000,000 | Strategy 5 Total |
| **Strategy 6: Expand the Talent Pipeline to Support Growth of the Autonomous Systems Industry** | | | | | | |
| | **Action 6.1:** Expand the talent pipeline through coordination across regional institutions | | $250,000 | | $250,000 | Pgh Tech Council to lead with PRN in collaboration with regional colleges and universities |
| | **Action 6.2:** Address current gaps in the region's autonomy industry talent base | | $500,000 | $500,000 | $500,000 | Pgh Tech Council to lead with PRN |
| | **Action 6.3:** Expand initiatives to attract new talent to the industry from outside the region | | | | $250,000 | Pgh Tech Council to lead with PRN |
| | | | $750,000 | $500,000 | $1,000,000 | Strategy 6 Total |
| | | **Total** | **$56,000,000** | **$20,000,000** | **$78,300,000** | **$154,300,000** |
| | | | State | Federal Funding | Local/ Regional | Combined Total |

The recommended additional strategic investment profiled on Table 7 will have a compounding effect on the deep investments already made or committed within the sector by leading regional organizations, philanthropies, universities, companies, and investors. It will be central in enabling the next level of growth in the cluster to occur, whereby R&D innovations will further translate into on-the-ground manufactured technologies and innovative business growth. The autonomous mobile systems and robotics ecosystem in the Pittsburgh region has experienced intensive recent investment in research and development infrastructure – with particularly robust investment taking place in R&D at Carnegie Mellon University, investment that, importantly, demonstrates a focus on applied research and engagement with industry. Table 7 summarizes recent signature investments relevant to the sector in the Pittsburgh region, showing **investment exceeding $490 million**. The strategies and actions outlined in this report are designed to build upon these existing investments, with additional public-private investments that strategically reinforce the ecosystem so that it may realize the full commercial promise of a fast growing, transformational industry sector.

**TABLE 7.**
**Recent Investments of Relevance to the Expansion of the Pittsburgh Autonomous Mobile Systems Ecosystem**

| Investment | Estimated Amount | Notes |
|---|---|---|
| Advanced Robotics for Manufacturing (ARM) Institute | $250 million | ARM funded by the Department of Defense and catalyzed by Carnegie Mellon. Both ARM and MFI (Manufacturing Futures Initiative at Mill 19), an interdisciplinary research initiative, were launched with the help of a $20 million gift from the Richard King Mellon Foundation, which provided significant support for research and the new Mill 19 facility. |
| RK Mellon Grant to Carnegie Mellon University | $150 million | $75 million for new science building on the Carnegie Mellon campus in Oakland, and $75 million for the robotics innovation center and an institute focused on advanced materials and manufacturing at Hazelwood Green. |
| Corporate Test Track Investments | >$50M | Over $50M in private investment commitment focused on testing facilities, tracks, and associated infrastructure. |
| Carnegie Mellon University-CCDC Army Research Laboratory Cooperative Agreement | $25 million | Carnegie Mellon University and the U.S. Army Combat Capabilities Development Command's (CCDC) Army Research Laboratory (ARL) have entered into a $3.5 million cooperative agreement that supports machine learning-enabled additive manufacturing to enhance the expeditionary manufacturing capability of the Army. The funding marks the beginning of a five-year program, led by CMU's College of Engineering, with the Army awarding up to four years and totaling as much as $25 million. |
| Argo AI Center for Autonomous Vehicle Research at Carnegie Mellon University | $15 million | A five-year, $15 million sponsored research partnership funding research into advanced perception and next-generation decision-making algorithms for autonomous vehicles. |
| US DOT Grant to HERL at the University of Pittsburgh | $1M | U.S. Department of Transportation awarded $1 million to the Human Engineering Research Laboratories (HERL) at the University of Pittsburgh, for a study of how automated vehicles can help people with disabilities. |
| RK Mellon Job Training & Career Readiness Grants | $250,000 + $125,000 | Advanced Robotics for Manufacturing Institute - $250,000 for the Keystone Space Collaborative. And, StartUptown - $125,000 to support the Pittsburgh Robotics Network's work to build a robotics industry cluster network of highly engaged stakeholders to fosters business growth and talent development. |
| RK Mellon Grant to Pittsburgh Robotics Network | $125,000 | June 2021 grant of $125,000 to support the continued growth of the Pittsburgh Robotics Network. |
| **Total** | **$491.5 million** | |

# In Conclusion

**An opportunity of this magnitude – an opportunity to lead in a fast growth technology sector and advanced industry – only presents itself rarely and has the potential to advance the region and state's economic development for decades to come. Public and private sector stakeholders in the region and the Commonwealth of Pennsylvania must act with urgency and purpose to capture the full potential for transformative economic growth the industry represents.**

# APPENDICES

## Appendix A

### MARKET RESEARCH ESTIMATES FOR VARIOUS AUTONOMOUS MOBILE SYSTEMS MARKET SPACES

| Autonomous Mobile Systems Sector | 2023-2026 Estimated Annual Output (Market Size) | Source |
|---|---|---|
| Autonomous on road vehicles (cars, trucks, buses, etc.) | $556.67 billion (2026) | *https://www.alliedmarketresearch.com/autonomous-vehicle-market* |
| Agricultural Equipment | $180 billion (2024) | *https://www.gminsights.com/industry-analysis/autonomous-farm-equipment-market?gclid=Cj0KCQjwh_eFBhDZARIsALHjlKcFiwxLb1_vE9ZYDuuTHMglaNQwfte kpwRw4sVaERVTm-SSFopOfhgaAvekEALw_wcB* |
| Construction Vehicles | $15.13 billion (2025) | *https://www.globenewswire.com/news-release/2021/05/24/2234570/28124/en/Global-15-13-Billion-Autonomous-Construction-Equipment-Markets-2015-2020-2020-2025F-2030F-Earth-Moving-Construction-Vehicles-Material-Handling-and-Concrete-Road-Construction.html* |
| Trains (passenger, freight, mining) | $10.8 billion (2025) | *https://www.globenewswire.com/news-release/2021/05/14/2229927/28124/en/Global-Autonomous-Trains-Passenger-Train-Freight-Mining-Market-*Report-*2021-Major-Players-are-Alstom-S-A-ABB-Bombardier-CRRC-Transportation-Hitachi-Kawasaki-Mitsubishi-Siemens-Thale.html* |
| Mining Equipment | $3.44 billion (2025) | *https://www.globenewswire.com/news-release/2021/05/07/2225496/0/en/Autonomous-Mining-Equipment-Global-Market-Report-2021-COVID-19-Growth-And-Change-to-2030.html* |
| Cleaning Robots | $24 billion (2026) | *https://www.globenewswire.com/news-release/2021/05/14/2229696/28124/en/Outlook-on-the-Cleaning-Robot-Global-Market-to-2026-by-Type-Product-Application-and-Region.html* |
| Logistics Robots | $12.81 billion (2025 interpolated) | *https://www.fortunebusinessinsights.com/logistics-robots-market-102923* |
| Total | $802.85 billion | |

# Appendix B

### CALCULATION OF AVERAGE JOB GENERATION IN MANUFACTURING ASSOCIATED WITH OUTPUT.

| | |
|---|---|
| 2019 Total U.S. Manufacturing Gross Output | $25,037,000,000,000 |
| 2019 Total U.S. Manufacturing Full and Part Time Workers | 12,797,000 |
| 2019 Average Output per Worker | $1,956,474.17 |
| 2019 Total U.S. Manufacturing Full-Time Equivalent Workers | 12,515,000 |
| 2019 Average Output per FTE Worker | $2,000,559.33 |

***Sources:*** *U.S. BEA Gross Output by Industry and Employees by Industry (Full Time & Part Time and Full-Time Equivalent).*

# Appendix C:
## Line of Sight Methodology for Identifying Strategic Opportunity Areas for Pittsburgh's Autonomous Systems Industry

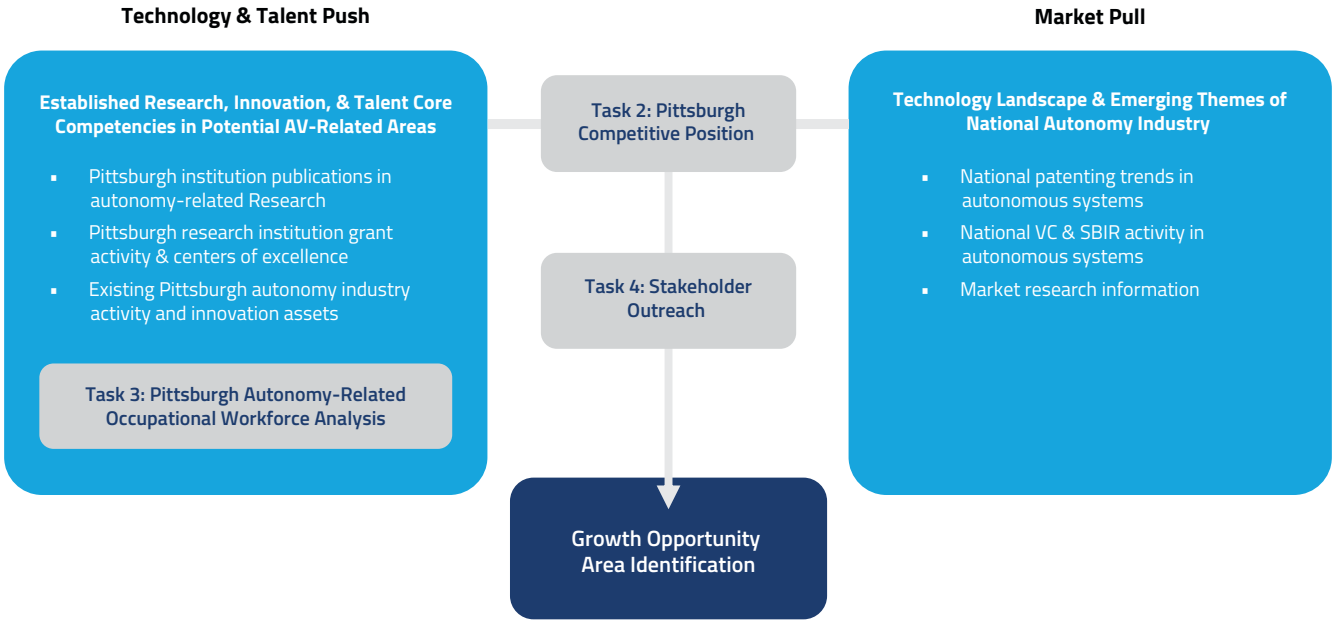
### Leveraging Line of Sight Analysis to Identify Strategic Opportunity Areas

For technology convergence industries that depend on the integration of multiple emerging digitally-based products and services, a region's research and development assets and the ability of its innovation ecosystem to translate those assets into new products and new businesses is a key determinant of economic growth. These areas of localized strengths in R&D assets reflect the core competencies around which those industries innovate and grow within specific cities and their surrounding regions. The concept of core competencies is now widely understood as a critical factor for industries to be competitive, and these regional specializations can be thought of as "bundle of skills and technologies" that enable innovation and growth, particularly for industries who depend on fast-moving digital technologies to enable them to bring products to market.

From a local and regional technology-based economic development perspective, core R&D and innovation competencies represent where a region has the "know how" across its industries and research institutions, involving universities, federal labs, and non-profit organizations, to position the region for future growth in targeted markets. Using the profile of a region's core competencies, it is possible to then examine the extent to which there are robust, strategic growth opportunities with capabilities supported by both research institutional and industry strengths where the Pittsburgh region is best positioned to differentiate itself. Strategic growth opportunities representing highly- aligned competency areas across industry and research institutions reflect the convergence, or "line-of-sight", where the region has the know-how and capacity to grow in the future.

The effect of core competencies and their respective lines of sight to market are especially relevant to the autonomous systems industry given its profile as a maturing, rapidly evolving technology-based industry cluster. To determine a line of sight for Pittsburgh's autonomous systems industry, TEConomy examined the region's core competencies and competitive position within the autonomous systems technology and industry landscape through a set of quantitative analyses. Figure x presents the overall approach used in this assessment to identify a "line-of-sight" to strategic growth platforms that consider the market pull of leading industry applications in autonomous mobile systems as well as the technology and talent push from the region's research and innovation capabilities.

**FIGURE C1.**
Line of Sight Analysis Approach Used to Evaluate Pittsburgh's Autonomous Systems Industry




Subsequent appendices outline the various analyses conducted in project tasks that were used to determine growth opportunity areas within autonomous systems. The goal of market pull analyses was to evaluate the current industry activity in autonomous systems technologies and end market applications based on a scan of current US market activity to identify major thematic areas of investment and innovation that could be the focus of economic development strategies while also highlighting any areas where Pittsburgh displays significant activity or focus. Similarly, analyses were used to evaluate the technology and talent push based on the Pittsburgh region's existing core competencies that can help support further development of the autonomous systems industry. These analyses then leverage the combination of market demand for innovative solutions and regional supply of innovation assets in combination with regional stakeholder outreach to identify strengths and gaps for the region that in turn highlight potential growth opportunities.

# Appendix D:
# Analyses of Leading Themes Driving Market Pull for Autonomous Systems

To analyze the thematic areas of market activity across the broader the autonomous systems sector, TEConomy took a national perspective that incorporated various measures industry innovation and investment from the broader industry base of the U.S. This perspective helped capture emerging trends in the U.S. autonomy market in a forward-looking way that then highlights potential opportunity areas for the Pittsburgh region to position itself to capitalize on and provides a perspective on the region's current scale of activity within the context of the whole.

Several sources of data on emerging technology and market applications were leveraged to help build a picture of the market landscape in autonomous systems, including:

- Trends in autonomy-related patenting, which highlights areas of innovation where companies are investing in generating intellectual property (IP)
- Federal Small Business Innovation Research (SBIR) grant awards for autonomy-related research, which highlights emerging research projects undertaken by small businesses in emerging technology areas
- Venture capital investment in autonomy-related companies, which highlights emerging companies developing autonomous systems technologies and services that are generating interest from investors
- Market research and other data sources, which were used to identify any other significant areas of investment in emerging autonomy-related technologies not captured by the data described above

## U.S. Patenting Trends in Autonomous Systems Technologies

U.S. patents related to autonomous systems were identified using technology classes listed in patent records published by the U.S. Patent and Trademark Office (USPTO) that document the specific technological focus of the intellectual property being described in conjunction with keyword analyses of patent titles and abstracts. This approach identified almost 10,500 patent records over the 2015-2020 time period documenting technologies that were highly related to the autonomous systems technology stack. As shown in Table D1 below, patenting volume in this space has increased dramatically over the last 5 years, indicating increased interest in establishing IP positions in emerging autonomous technologies as the technology space begins to mature.

**TABLE D1.**
U.S. Patenting Trends in Autonomous Systems Technologies, 2015-2020

| Year | Autonomy-Related Patent Applications | Autonomy-Related Patent Awards | Total Autonomy-Related Patent Records |
|---|---|---|---|
| 2015 | 115 | 462 | 577 |
| 2016 | 171 | 537 | 708 |
| 2017 | 295 | 782 | 1077 |
| 2018 | 565 | 1,133 | 1,698 |
| 2019 | 1,223 | 1,447 | 2,670 |
| 2020 | 2,013 | 1,718 | 3,731 |
| Total | 4,382 | 6,111 | 10,493 |

***Source:*** *TEConomy analysis of USPTO data, retrieved from Derwent Innovation*

Figure D1 below shows the focus areas of these patents as detailed by the leading technology classes listed in patent records with 50 or more records over the 2015-2020 time period. A majority of the documented IP in leading technology class areas is focused on the autonomous vehicles sector, particularly around automated navigation systems and supporting data fusion and localization.

**FIGURE D1.**
## Portfolio of Leading Patent Technology Areas in US Autonomy-Related Patenting, 2015-2020


As demonstrated by the technology focus of patent records, leading companies in patenting activity are highly concentrated in the driverless car sector with major auto manufacturers and tech companies with driverless car initiatives displaying especially high activity levels over the last 5 years (see Table D2 below). Additional activity in autonomous logistics and delivery applications by major fulfillment companies also demonstrates a focus on autonomous materials handling and delivery systems.

**TABLE D2.**
## Leading Companies Involved in Autonomy-Related Patenting Activity, 2015-2020

| Primary Company Assignee | Primary Focus of Patenting Activity | Patent Applications | Patent Awards | Total Patent Records |
|---|---|---|---|---|
| Uber Technologies Inc. | Autonomous car sensing & AI | 201 | 208 | 409 |
| Ford Global Technologies LLC | Autonomous cars & associated subsystems | 116 | 206 | 322 |
| Waymo LLC | Autonomous cars & associated AI | 107 | 211 | 318 |
| GM Global Technology Operations LLC | Autonomous cars & associated subsystems | 120 | 178 | 298 |
| Amazon Technologies Inc. | Autonomous delivery & material handling systems | 22 | 255 | 277 |
| International Business Machines Corporation | Autonomous vehicle perception, navigation, & interaction | 97 | 167 | 264 |
| Baidu USA LLC | Autonomous cars & associated AI | 118 | 110 | 228 |
| Walmart Apollo LLC | Autonomous storage, retrieval, & delivery systems | 108 | 75 | 183 |
| Intel Corporation | Autonomous system perception & embedded computing hardware | 111 | 71 | 182 |
| iRobot Corporation | Autonomous mobile maintenance & cleaning robots | 49 | 125 | 174 |
| State Farm Insurance Company | Autonomous vehicle operation & safety monitoring | 9 | 161 | 170 |
| Qualcomm Incorporated | Communication & control technologies for autonomous systems | 77 | 90 | 167 |
| Google Inc. | Perception & AI software for autonomous systems | 8 | 153 | 161 |
| The Boeing Company | Unmanned aerial vehicles & automated inspection systems | 37 | 108 | 145 |
| Toyota Motor Engineering & Manf. North America Inc. | Autonomous cars & associated subsystems | 26 | 107 | 133 |
| Zoox Inc. | Autonomous vehicle sensing, perception, & fleet management | 57 | 64 | 121 |

***Source:*** *TEConomy analysis of USPTO data, retrieved from Derwent Innovation*

As shown in Table D3, the Pittsburgh region has a significant footprint within the national patenting landscape. There is significant patenting activity by Pittsburgh inventors in the autonomous systems space, totaling 4.4% of national volume over the 2015 to 2020 period. However, this activity is highly concentrated within IP that was originally assigned to Uber Autonomous Vehicle (Uber ATG) operations which was subsequently acquired by Aurora Innovation. There are an additional 14 companies headquartered in the Pittsburgh region that were identified as having at least 1 patent record from over the time period, many of which are startups or small businesses.

## TABLE D3.
## Pittsburgh Autonomy-Related Patenting Activity, 2015-2020

| Primary Company Assignee | HQ in Pgh Region? | Primary Focus of Patenting Activity | Patent Applications | Patent Awards | Total Patent Records |
|---|---|---|---|---|---|
| Uber Technologies Inc. | | Autonomous cars | 153 | 179 | 332 |
| Aurora Innovation Inc. | | Autonomous vehicle navigation & testing | 10 | 7 | 17 |
| Carnegie Mellon University | yes | Autonomous robotics & vehicles | 4 | 7 | 11 |
| Kespry Inc. | | UAV navigation & recovery | 3 | 8 | 11 |
| GM Global Technology Operations LLC | | Autonomous vehicle perception & reaction | 4 | 5 | 9 |
| Caterpillar Inc. | | Autonomous work vehicle control | 2 | 4 | 6 |
| Aptiv Technologies Limited | | Autonomous vehicle sensing | 5 | 1 | 6 |
| Near Earth Autonomy Inc. | yes | Autonomous rotorcraft control | 1 | 3 | 4 |
| Discovery Robotics | yes | Service robot planning/logic | 3 | 1 | 4 |
| Bossa Nova Robotics IP Inc. | yes | Stock monitoring robots | 3 | 1 | 4 |
| Robert Bosch GmbH | | Autonomous vehicle sensing | 1 | 3 | 4 |
| Duality Robotics Inc. | | Robotic simulation environments | 3 | | 3 |
| Argo AI LLC | yes | Sensor data fusion | 2 | | 2 |
| Neya Systems LLC | yes | Autonomous multi-vehicle convoys | 2 | | 2 |
| RoBotany Ltd. | yes | Autonomous agriculture management | 2 | | 2 |
| Advanced Construction Robotics Inc. | yes | Autonomous transportation & assembly | 1 | 1 | 2 |
| IAM Robotics LLC | yes | Autonomous storage & retrieval | 1 | 1 | 2 |
| RedZone Robotics Inc | yes | UAV sensing | | 1 | 1 |
| Aethon Inc. | | Autonomous mobile delivery robotics | 1 | 1 | 2 |
| BITO Robotics | yes | Autonomous mobile loading robot | 1 | 0 | 1 |
| Locomation | yes | Autonomous vehicle sensing | 1 | 0 | 1 |
| Identified Technologies Corp. | yes | UAV manufacturing | | | |
| Total, all Pittsburgh Region-Invented Patents | | | 220 | 242 | 462 |

***Source:*** *TEConomy analysis of USPTO data, retrieved from Derwent Innovation*

## U.S. Autonomy-Related Venture Capital Investment & SBIR Award Activity

To understand activity in emerging innovative companies focused on autonomous systems applications, TEConomy analyzed both Federal Small Business Innovation Research (SBIR) grant awards for autonomy-related research as well as venture capital investment in companies providing autonomous systems products and services. Risk capital investment and SBIR awards both represent a significant milestone in the commercialization process where capital is being actively deployed to fund innovative concepts either by the federal government or private investors.

Using investment in emerging, innovative companies as an indicator of market trends is especially relevant for autonomy-related technologies. Both types of activity are focused on innovation that displays near-term pathways to market, meaning companies receiving VC or SBIR investment will tend to be more focused on the market or mission applications of autonomy that give insights into practical usage rather than more abstract basic research focused on enabling capabilities. Autonomy technologies also may not be as widely documented in other innovation indicators due to desire to maintain competitive advantage in a fast-moving market.

TEConomy used a joint analysis of traditional venture capital investment (excluding mergers and acquisitions as well as direct corporate investment) to identify thematic areas of convergence in market applications. By examining these two investment indicators jointly, it is possible to more comprehensively determine overarching emerging technology themes present across both federal and private markets. Autonomous systems-related companies receiving traditional VC investment were identified using key technology and market verticals from the Pitchbook venture capital database in combination with keyword searches of company descriptions. Similarly, companies receiving SBIR awards that were related to autonomous systems were identified using a combination of awarding agency (with most autonomous systems activity located in Department of Defense, National Science Foundation, Department of Energy, NASA, and other non-biomedical focused funding agencies) and keyword searches of award titles and abstracts.

The data used in the analysis of technology themes present in market activity is shown below in Table x. Autonomous mobile systems companies in the Pittsburgh region comprised 1.5% of all U.S. companies receiving mobile autonomy-related SBIR awards and 3% of all awarded dollars from 2015 to present, while regional companies comprised 2.5% of all mobile autonomy-focused U.S. companies receiving traditional VC investment and 1.7% of all funded dollars from 2015 to present.

**TABLE D4.**
### Summary of Data Used in Analysis of Venture Capital & SBIR Activity Themes from 2015-present

| | SBIR Awards* | VC Investment** |
|---|---|---|
| Total Companies | 1,003 | 1,112 |
| Total Pittsburgh Companies | 15 (1.5%) | 28 (2.5%) |
| Total Dollars Awarded ($M) | $1,035 | $88,447 |
| Total Dollars Awarded Pgh ($M) | $31 (3%) | $1,527 (1.7%) |

**Uses latest available SBIR award data, partially available through 2020 at time of analysis*

***All companies receiving at least some venture investment during time period, not including M&A and solely corporate-backed funding*

***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

To identify thematic areas of market pull present across VC and SBIR awards, TEConomy leveraged a network analysis that helps outline the landscape of emerging technology areas utilizing machine learning and natural language processing to

understand the contextual nature of commercialization activity. Networks help to visualize the relationships between the technologies and market applications areas being advanced based on the unstructured text content present in the titles and abstracts of SBIR awards and detailed descriptions of companies receiving VC investment.

Comparing similarities across the individual text records yields "connections" between records which build out the network of relationships within the collective body of unstructured text describing innovative industry activity in autonomous systems. Community detection algorithms can then use the structure of this network to identify clusters of highly connected records that have common technology or market application themes which give insights about the emerging market applications being advanced by industry. Figure D2 below illustrates the process of constructing the network from SBIR and VC records and analyzing its thematic landscape.

**FIGURE D2.**
**Thematic Network Analysis Methodology**

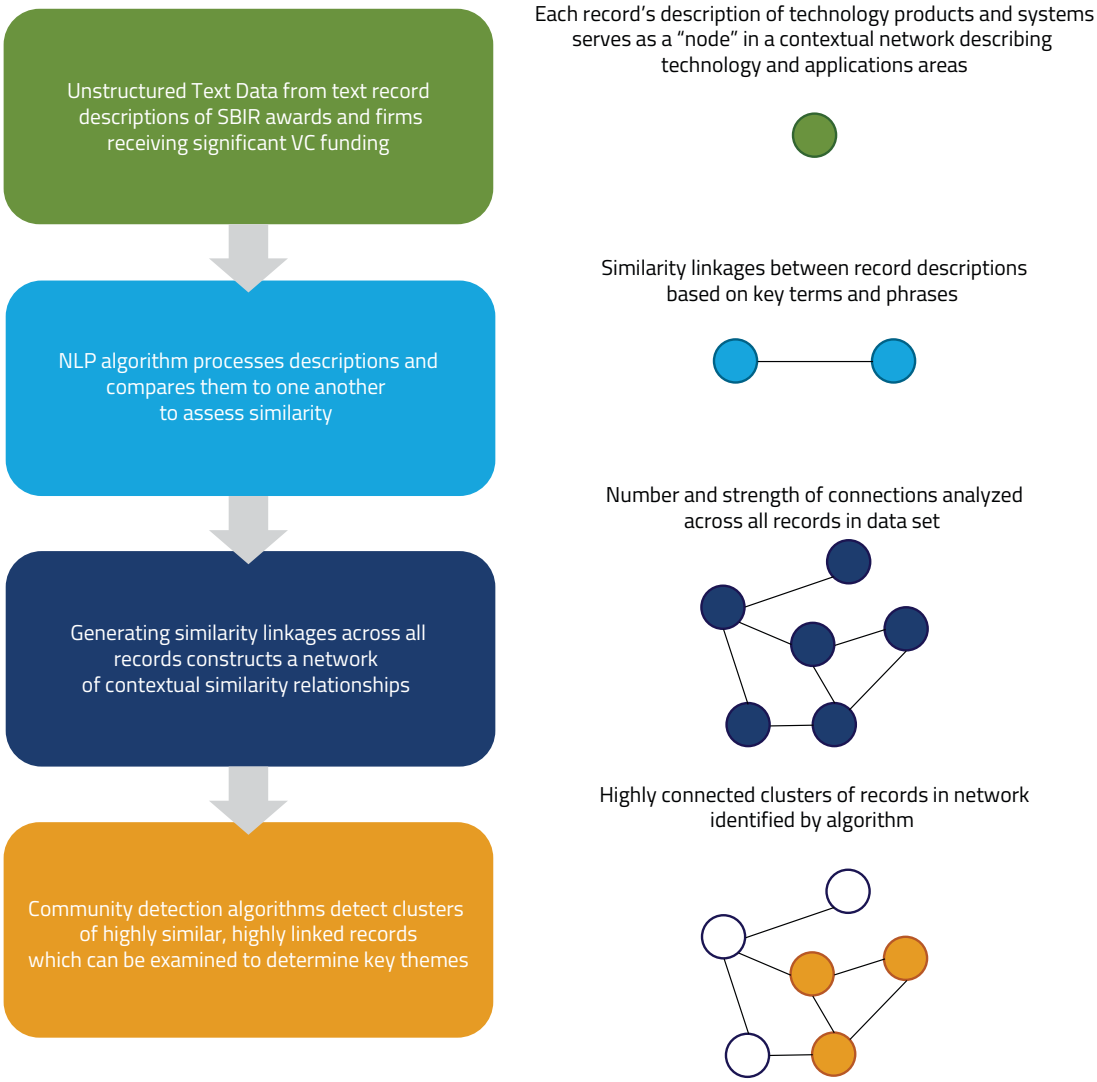
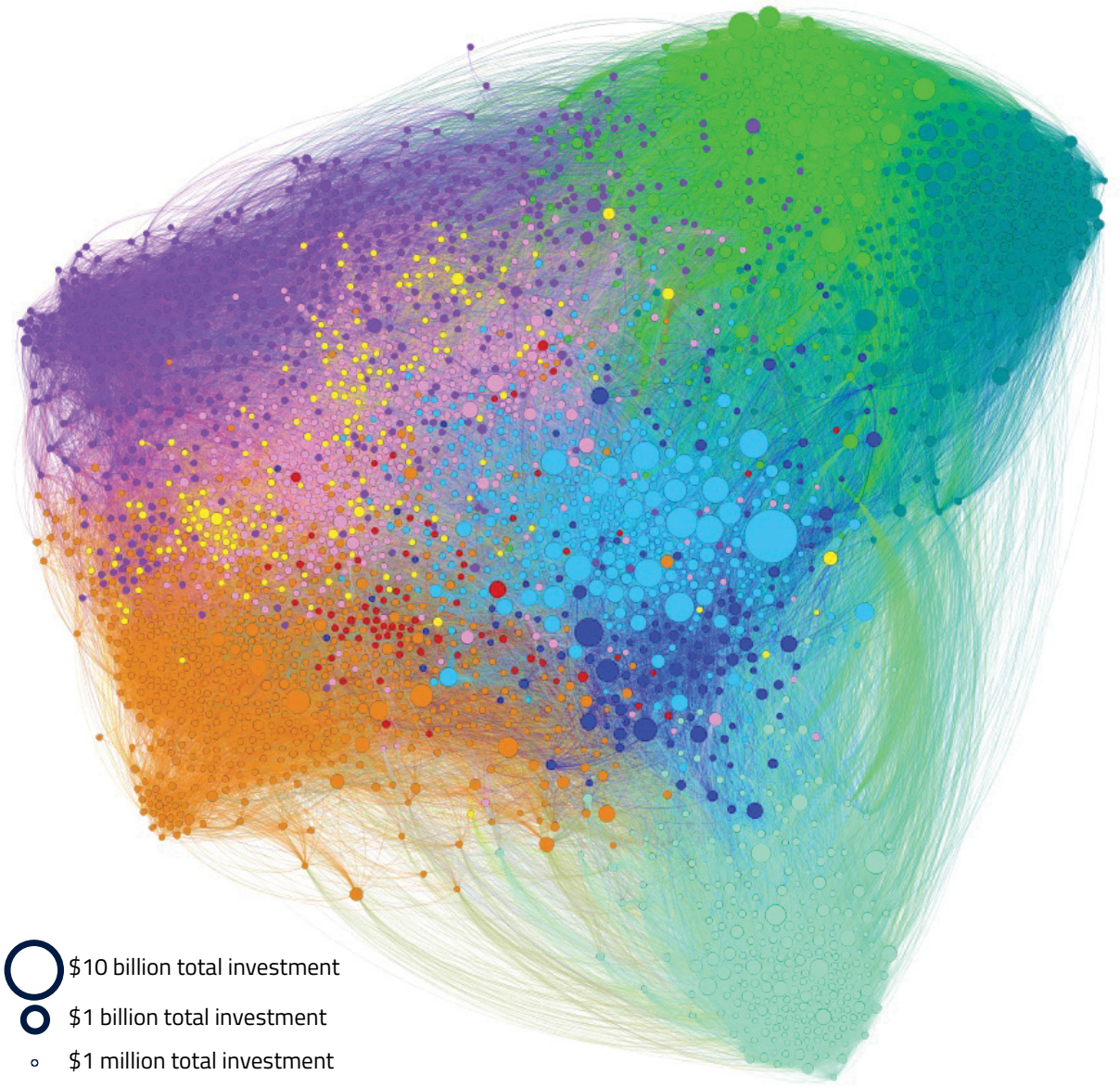


Figure D3 below shows the results of the thematic analysis, representing the national autonomous systems industry innovation activity landscape as seen through the lens of SBIR and venture capital activity. The size of nodes in the network diagram indicates the total dollars invested or awarded to a company to date across all funding rounds for VC investment, or the 2015-present total amount of SBIR funding received.

**FIGURE D3.**
**US Autonomy-Related Innovation Activity Landscape Represented by VC & SBIR Investment, 2015-present**

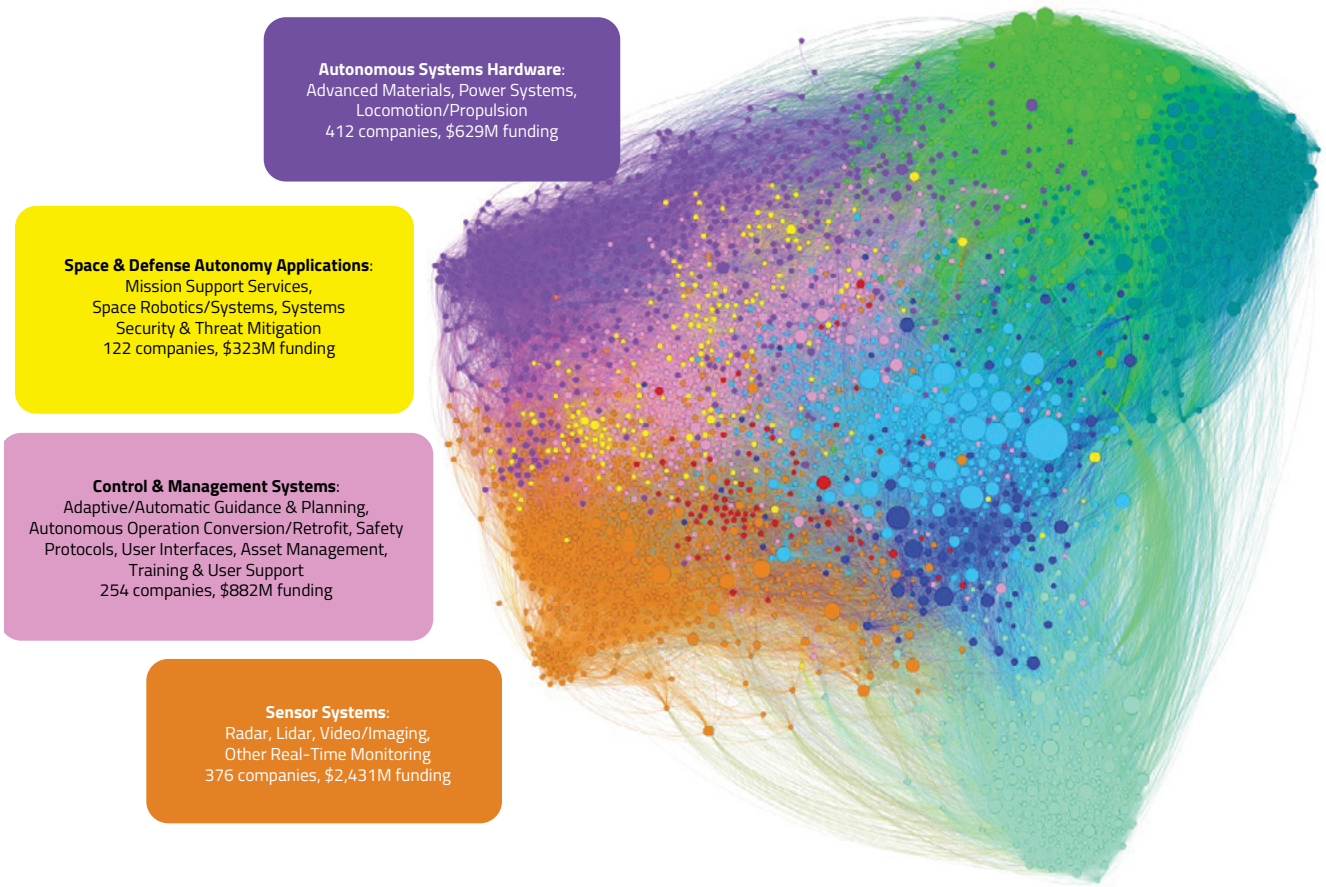



***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

The node colors represent major thematic clusters of autonomy-related innovation identified by community detection algorithm analysis. The ten identified clusters that outline the major themes of innovation activity in U.S. autonomous systems companies are detailed in Figures D4 and D5, as well as Table D5 below. These thematic clusters include technology applications focused on:

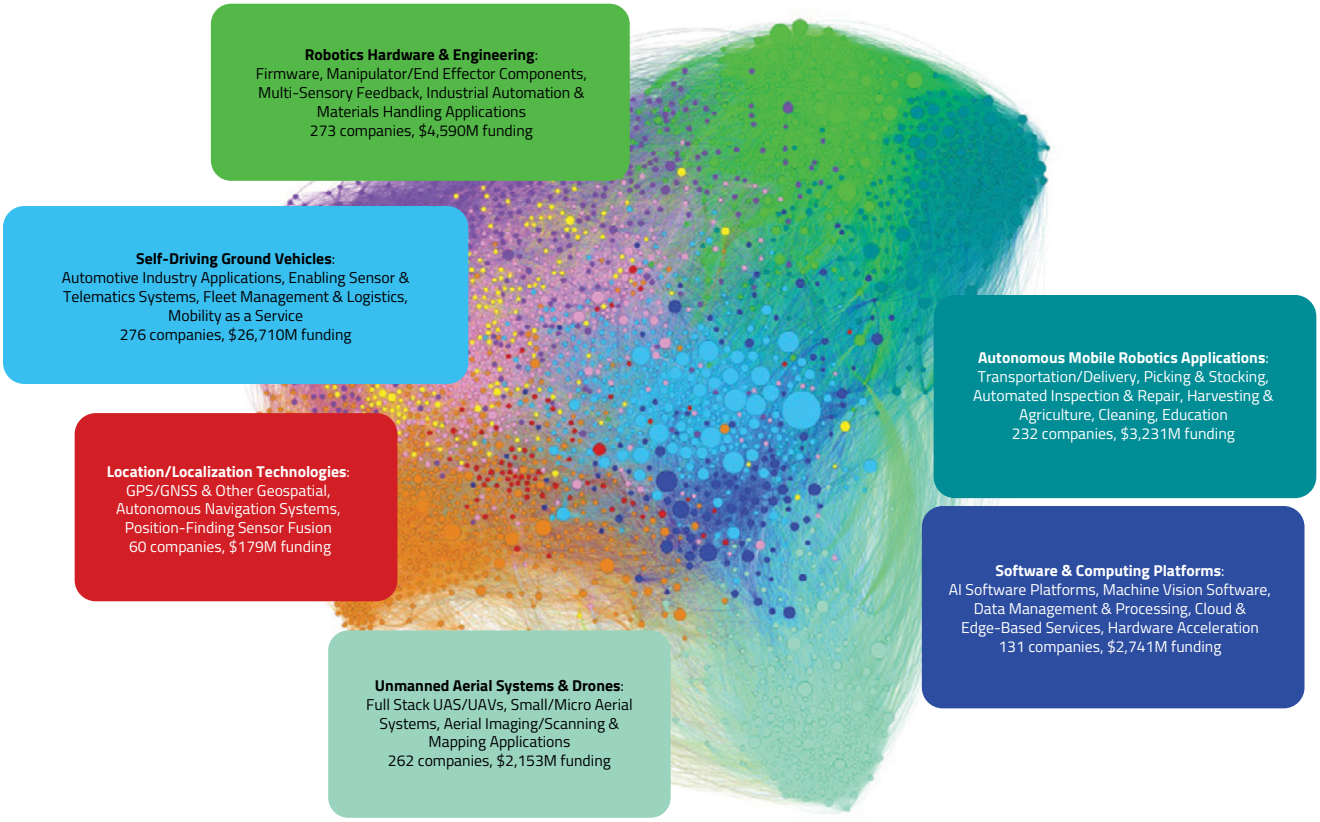
- **Self-Driving Ground Vehicles,** focused primarily on on-road autonomous cars but also including trucking and off-road applications
- **Robotics Hardware and Engineering,** focused on robotic systems components such as manipulators and end effectors but also including embedded sensing and firmware applications
- **Autonomous Mobile Robotics Applications**, focused on specific end market environment applications for AMRs in transportation and delivery, logistics and warehousing, cleaning, harvesting and agricultural tasks, and education
- **Software and Computing Platforms**, primarily focused on 3rd party providers of SaaS/PaaS solutions in enabling technologies for automation such as machine vision, cloud and edge computing, hardware acceleration, AI, and data management
- **Sensor Systems,** focused on systems used in autonomous solutions such as lidar, radar, video and other image capture, and real-time electromechanical monitoring
- **Unmanned Aerial Systems and Drones**, focused on full stack aerial systems spanning consumer to defense markets but also including some related services using aerial platforms for imaging and mapping
- **Control and Management Systems,** which provide systems engineering, management, safety, and user interface functionalities for autonomous systems
- **Autonomous Systems Hardware,** focused on the physical materials and components used to build autonomous systems such as power systems and locomotion/propulsion subsystems
- **Space and Defense Autonomy,** focused on specific mission-enabling and support tasks for national defense and space end applications
- **Location/Localization Technologies,** providing geospatial and other position-finding services, technologies, or data to enable autonomous systems operations

## FIGURE D4.
## Thematic Clusters Present in US Autonomy-Related Innovation Activity Landscape




***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

## FIGURE D5.
## Additional Thematic Clusters Present in US Autonomy-Related Innovation Activity Landscape




***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

**TABLE D5.**
## Summary of Thematic Cluster Analysis of US Autonomy-Related VC & SBIR Awards, 2015-present

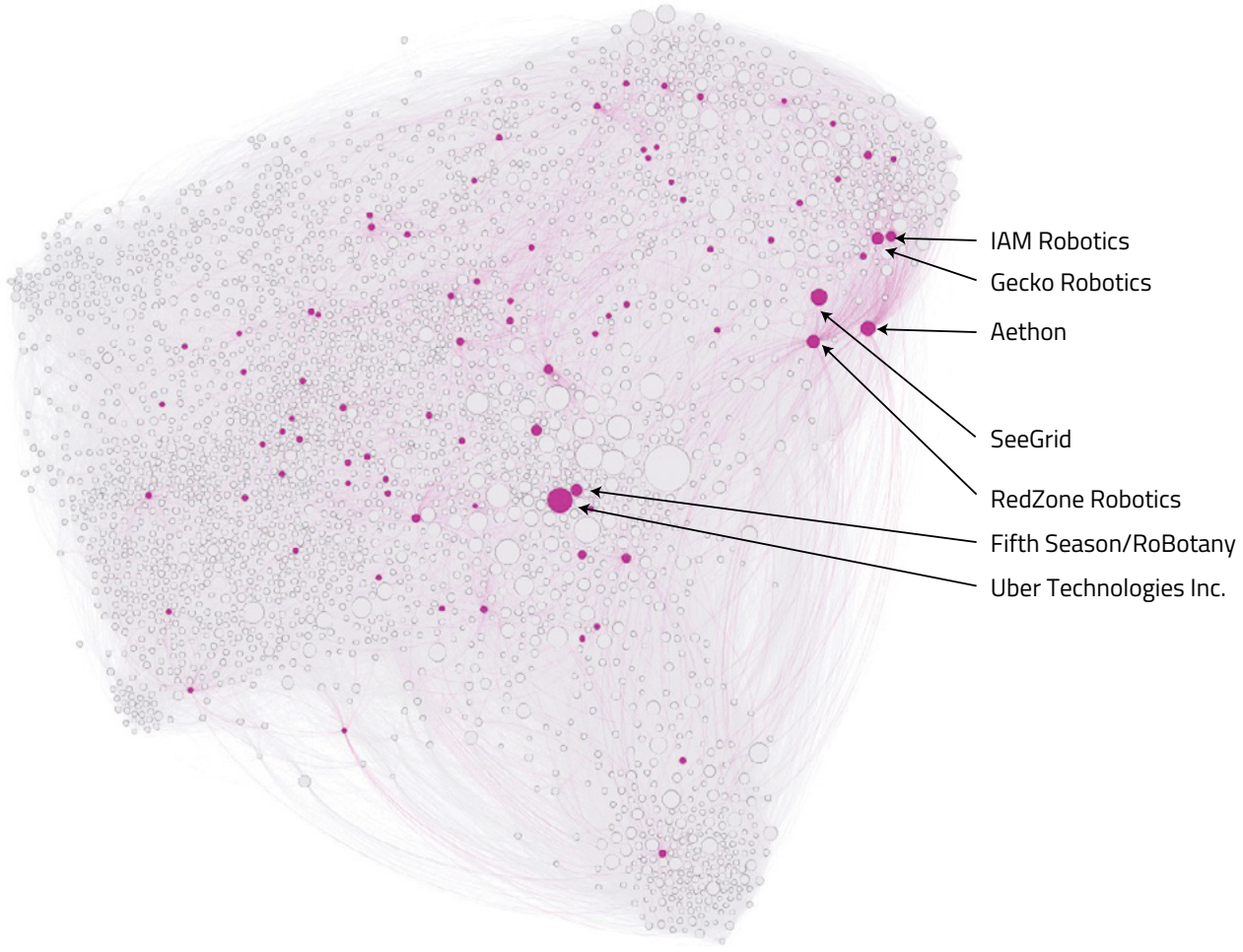
| Cluster | Number of Companies | Percentage of Companies | Total Dollars Invested (M) | Percentage of Total Dollars Invested |
|---|---|---|---|---|
| Self-Driving Ground Vehicles | 276 | 11.5% | $26,710 | 60.9% |
| Robotics Hardware and Engineering | 273 | 11.4% | $4,590 | 10.5% |
| Autonomous Mobile Robotics Applications | 232 | 9.7% | $3,231 | 7.4% |
| Software and Computing Platforms | 131 | 5.5% | $2,741 | 6.2% |
| Sensor Systems | 376 | 15.7% | $2,431 | 5.5% |
| Unmanned Aerial Systems and Drones | 262 | 10.9% | $2,153 | 4.9% |
| Control and Management Systems | 254 | 10.6% | $882 | 2.0% |
| Autonomous Systems Hardware | 412 | 17.2% | $629 | 1.4% |
| Space and Defense Autonomy | 122 | 5.1% | $323 | 0.7% |
| Location/Localization Technologies | 60 | 2.5% | $179 | 0.4% |
| | | | $43,869 | |

***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

As noted in Table x above, the vast majority of dollars invested over the past five years (nearly 61%) are aimed at advancing technologies associated with self-driving ground vehicles, in particular autonomous vehicles. Although the number of companies operating in each thematic area is far more distributed, the disproportionate share of investment focused on AV-related businesses speaks to the significant levels of corporate attention the space has attracted in recent years.

As highlighted below in Figure D6, the Pittsburgh region's footprint within the national landscape spans a variety of thematic areas, and includes activity focused in autonomous vehicles at the center of the network. Regional companies account for approximately 3.5% of the total U.S. autonomy-related investment dollars represented in this landscape (for reference, the Bay Area, CA accounts for approximately 27%). The largest investment activity anchored by Uber Technologies whose assets have since been acquired by Aurora Innovation, but there is also significant presence of activity in applied robotics and a cohort of companies active throughout the sensing, location/localization, and control systems themes. This breadth of coverage within the technology landscape indicates a wider portfolio of industry innovation happening in the region despite the investment volume in autonomous cars.

**FIGURE D6.**
**Highlighting Pittsburgh's Footprint in Autonomy-Related Innovation Activity Landscape Represented by VC & SBIR Investment**




***Source:*** *TEConomy analysis of Pitchbook VC data, US SBIR grant data*

Closer examination of specific companies receiving venture capital and SBIR awards in the Pittsburgh region demonstrates the area's broader diversity. Table D6 shows the leading autonomy-related companies in the region receiving VC investment over the 2015-present time period (not including mergers, acquisitions or other solely corporate-backed investment), while Table x shows leading regional autonomy-related companies receiving SBIR awards over the same period. Although the large venture investment in Uber ATG tops the group of Pittsburgh companies, there are many other notable businesses focused on AMRs and traditional robotic platforms such as Seegrid and Aethon that have received significant levels of investment, indicating they are developing mature product solutions with proximity to real markets. Similarly, the region's SBIR awards are focused around innovative applications in non-vehicle robotics platforms that highlight a diversified set of emerging companies.

## TABLE D6.
## Leading Autonomy-Related Companies in Pittsburgh Region Receiving Venture Capital* Investment, 2015-present

| Company | Company Focus | Total VC Investment Raised to Date ($M) |
|---|---|---|
| Uber Advanced Technologies Group | Developer of autonomous car sensor platforms and systems | 1,000.0 |
| Seegrid | Developer of autonomous industrial vehicles, autonomous mobile robots, and material handling automation solutions | 152.48 |
| Aethon | Developer of autonomous mobile delivery robots | 100.0 |
| RedZone Robotics | Provider of robots and software tools for wastewater asset management services | 58.6 |
| Gecko Robotics | Developer of robots intended to automate infrastructure inspections | 47.1 |
| Fifth Season | Developer of robotics-driven indoor vertical farming system | 37.8 |
| Locomation | Developer of human-guided autonomous trucking convoy technology | 28.5 |
| IAM Robotics | Manufacturer of autonomous mobile manipulation and picking robots | 20.7 |
| Edge Case Research | Developer of autonomous vehicle safety and software testing systems | 15.0 |
| Maven Machines | Developer of fleet management and telematics platform with applications in autonomy | 13.4 |
| RoadBotics | Developer of computer vision technology designed to inspect roads and infrastructure | 12.4 |

***Note:** for context of national innovation landscape analysis, venture capital does not include mergers and acquisitions or other solely corporate-backed investment. There was significant corporate-backed investment in several Pittsburgh-related companies since 2015 including $2.6B corporate financing investment in Argo AI in 2020 (Ford/VW), formation of Motional as a $4B joint venture between Aptiv/Hyundai in 2020, and acquisition of UATC by Aurora for $4B in 2020*

***Source:** TEConomy analysis of Pitchbook VC data*

## TABLE D7.
## Leading Autonomy-Related Companies in Pittsburgh Region Receiving SBIR Grant Awards, 2015-present*

| Company | Innovation Focus of SBIR Award Activity | Total SBIR Awards, 2015-present* | Total Awarded Amount ($M) |
|---|---|---|---|
| Near Earth Autonomy Inc. | Unmanned aerial system guidance and navigation, UAS mapping | 18 | 9.8 |
| RE2 Robotics Inc. | Various robotics platforms, exoskeletons, autonomous control refit | 7 | 6.0 |
| Neya Systems LLC | Unmanned systems perception, communications | 4 | 3.1 |
| ProtoInnovations LLC | Robotic planetary rovers, all-terrain mobility controls | 8 | 2.9 |
| Astrobotic Technology Inc. | Robotic planetary rovers, cooperative robots | 10 | 2.5 |

| Company | Innovation Focus of SBIR Award Activity | Total SBIR Awards, 2015-present* | Total Awarded Amount ($M) |
|---|---|---|---|
| Edge Case Research Inc. | Anomaly detection, sensor simulation | 3 | 2.1 |
| Nokomis Inc. | Target detection and identification, drone aircraft | 8 | 1.5 |

**Uses latest available SBIR award data, partially available through 2020 at time of analysis*

***Source:*** *TEConomy analysis of US SBIR grant data*

In addition to more traditional venture funding, Pittsburgh has demonstrated major success in the autonomous vehicles sector in attracting signature corporate investment from major automotive manufacturers. Beginning in 2015 with the opening of Uber Advanced Technologies Group (ATG) in Pittsburgh, the region's autonomous cars companies have continued to drive employment growth, investment, and national attention towards the local industry sector. These efforts culminated in 2020 with multi-billion dollar investments across several different Pittsburgh autonomous vehicles companies representing a significant milestone for the industry cluster's growth. Major automotive manufacturers made signature investments in Argo AI ($2.6 billion from Ford and Volkswagen), helped form Motional as a joint venture ($4 billion joint venture between Aptiv and Hyundai with significant operations in Pittsburgh), and AV company Aurora acquired Uber ATG's operations (acquisition deal valued at $4 billion, Aurora is partnered with Volvo and Honda).

As shown below in Table D8, the region has been able to capture an outsized share of this type of funding encompassing mergers and acquisitions as well as other direct corporate investment in key autonomous vehicle-related industry verticals (collectively referred to hereafter as M&A deals or investments), demonstrating the importance this source of funding has had on the growth of the sector locally. Pittsburgh companies were involved in 5 major M&A deals in the autonomous cars sector over the 2015 to present time period, but these deals collectively represented over $7.6 billion and over 28% of all dollars invested in this industry vertical nationally over that time span. The region has also captured a significant share of M&A investment in the AI and machine learning industry vertical totaling almost $8.7 billion which equates to 14.5% of all U.S. dollars invested in this industry vertical from 2015 to present. Conversely, despite its research strengths the region has not captured a large share of the national M&A or traditional VC investment in robotics and drones. Traditional VC investment more broadly does not display the same level of outsized market share relative to M&A investment for the region across these key market verticals, emphasizing the degree to which the region's funding supporting growing autonomous systems companies has flowed from direct investment from larger corporate sponsors and partners. While these signature investment deals have allowed the autonomous systems sector to grow dramatically in recent years, this does highlight a level of dependence on M&A investment for the region's industry that may not be sustainable over decades and may not be accessible to the wider community of emerging entrepreneurial companies.

**TABLE D8.**
**Share of U.S. Mergers, Acquisitions, and Direct Corporate Funding vs. Traditional Venture Capital Investment in Pittsburgh Companies in Autonomous Systems-Related Industry Verticals, 2015-present**

| Industry Vertical | Pgh Share of National M&A Deals | Pgh Share of National M&A Dollars Invested | Pgh Share of National VC Deals | Pgh Share of National VC Dollars Invested |
|---|---|---|---|---|
| All Industries | 0.8% | 1.1% | 0.8% | 0.4% |
| Artificial Intelligence & Machine Learning | 1.4% | 14.5% | 1.1% | 1.2% |
| Autonomous Cars | 7.5% | 28.2% | 2.1% | 4.1% |
| Robotics and Drones | 1.7% | 0.2% | 3.1% | 1.1% |

***Source:*** *TEConomy analysis of Pitchbook VC data*

## Conclusions from Analysis of National Autonomous Systems Market Pull

Analyses of national activity in autonomous systems highlight autonomous vehicles as the key technology platform driving innovation and investment in recent years. The overwhelming level of industry-facing investment in this applications space highlights the central role the autonomous car industry plays in driving innovation across the broader autonomous systems sector and demonstrates the level of industry anticipation of major emerging markets in this area. Driverless vehicle industries are a key downstream user of fundamental sensing, machine vision/perception, and systems management technologies, which has also driven fundamental advancements in the state of upstream technologies to meet the need for improved outcomes in prototyping and testing of AVs.

Mobile autonomous robotics platforms, in particular AMR solutions, are also a major innovation theme, with markets driven by efficiency and cost-savings implications for a variety of logistics-focused industry sectors. Major investments in this thematic space are being driven by automation solutions for supply chain storage and retrieval tasks given labor supply and cost pressures on traditional materials handling and moving business operations. There is also increasing usage of these solutions in automation of inspection and other information gathering tasks by manufacturing, transportation, and materials handling industries as they look to streamline maintenance and repair processes.

Unmanned aerial systems represent an additional differentiated market that has critical mass, but operates under market dynamics more driven by national defense and research needs. Applications in this sector tend to be driven by defense and aerospace contractors responding to military and defense missions or security and surveillance needs, or by researchers seeking to leverage remote sensing capabilities for data gathering. An emerging area for industry applications more broadly is focused on the new services enabled by aerial drone platforms and their ability to gather cost effective mapping and visualization data, often leveraging off the shelf platforms in conjunction with innovative sensing or machine learning applications to generate software and decision support products.

Many other niche markets exist, but do not yet show a similar critical mass of innovation or investment activity. Examples of such market applications include marine, space, and personal robotics systems.

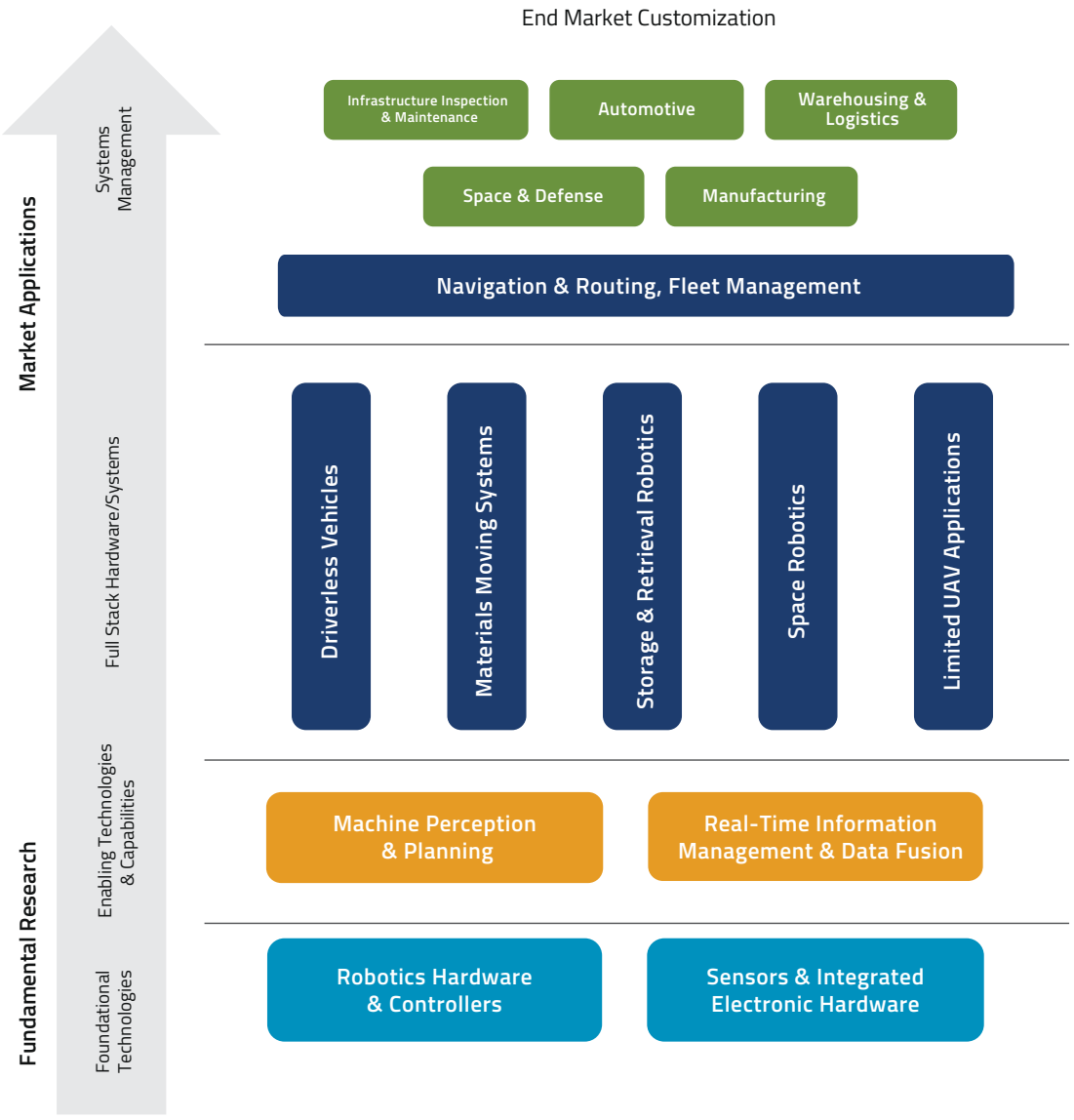
The analyses of the national autonomous systems market also highlight a key technology convergence area around integrated offerings combining AI and machine learning, sensing hardware, location/localization technologies, and software platforms. As noted above, this trend is enabled by affordable, modular "off the shelf" autonomous systems platforms (such as quadrotor drones) that can be outfitted with specific sensing hardware and supported by scalable AI and edge computing solutions to enable new services. Similarly, larger scale autonomous vehicle companies often are not focused on manufacturing of the core vehicle and instead pursue innovation in sensing and perception systems as well as improvements to the algorithms driving improved performance. These trends highlight the role of data fusion in enabling scalable, efficient perception and response by autonomous systems that are made up of a variety of subsystems. Additionally, the market applications outlined in these analyses show that AI computing and processing is increasingly being embedded into systems to enable them to operate in a variety of environments in an infrastructure-agnostic way.

Even though it has not expanded to the same scale as other leading regions (such as the Bay Area), Pittsburgh still captures a significant share of national autonomy-related market-facing innovation activity. The volume of activity is driven disproportionately by the presence of leading companies focused on driverless cars, but there is evidence that the scope and scale of innovation is driven more broadly by a cohort of small and mid-sized companies leveraging innovative robotics and sensing technologies for a diverse set of applications. Key market-facing technology drivers for the region also observed across national markets include:

- Autonomous passenger vehicles
- Applied robotics, serving a variety of markets including space systems, defense, materials handling and logistics, manufacturing, and infrastructure
- Sensor hardware and associated data streams/data fusion

Figure D7 summarizes Pittsburgh's market-facing areas of activity, as outlined by the set of quantitative analyses above, within the context of the autonomy technology stack. Note that this does not represent a complete view of Pittsburgh's activity or competencies, but rather the perspective given by technology and innovation indicators that describe the broader U.S. market for autonomous systems.

**FIGURE D7.**
Pittsburgh's Market-Facing Technology Drivers Shown Within the Context of the Autonomous Systems Technology Stack



# Appendix E:
## Analyses of Pittsburgh's Core Competencies Driving Technology Push

The Pittsburgh region's research enterprise represents a key asset that feeds the local innovation ecosystem and can be leveraged towards creating a strong autonomous systems industry presence. TEConomy employed several sources of data documenting research activity to help identify underlying core competencies that directly support the autonomous systems industry, including:

- Research publication activity and key themes, which highlight areas of research from Pittsburgh's institutions that are aligned with autonomy-related capabilities
- Grant awards and research funding levels, which highlight areas of focused investment in differentiated research capabilities

Autonomy-Related Research Publications Activity at Pittsburgh Institutions

Research that has applications to autonomous systems spans a number of different scientific discipline areas including engineering, computer sciences, physics, and materials sciences. One way to examine the extent to which a region is engaging in research activity that can help support autonomous systems innovation is to analyze research publications being generated by regional institutions that potentially align with autonomy-related research fields.

TEConomy leveraged the Clarivate Web of Sciences science journal indexing database to analyze research publications for the Pittsburgh region, a service that documents peer-reviewed journal publications and conference proceedings encompassing a broad array of disciplines and high impact journals. In order to identify research publications that had potential relevance to autonomous systems, the analysis was limited to a subset of research disciplines that were most aligned with the context of the autonomous systems technology stack. Scientific disciplines included in the context of the analysis encompassed four main groups:

- Engineering disciplines such as electrical and mechanical engineering, excluding biomedical and other engineering disciplines that are less relevant to autonomous and robotic systems
- Computer science disciplines, encompassing both fundamental research as well as applied areas of AI and networking
- Mathematics and statistics disciplines, including both fundamental and applied research areas but excluding social sciences-related mathematical disciplines
- Other potentially aligned physical sciences disciplines such as applied physics and portions of materials sciences

This approach identified 14,623 peer-reviewed publications from Pittsburgh institutions over the 2016-present time period. The leading discipline areas present in this set of research publications are shown below in Table E1. Research disciplines that are 20% or more concentrated within Pittsburgh's publishing activity patterns relative to national publishing activity are considered specialized, indicating areas of potential competitive advantage and research leadership. The publications specialization index shown below captures this perspective, with research areas that meet the threshold for regional specialization highlighted in bold.

**TABLE E1.**
**Share of U.S. Mergers, Acquisitions, and Direct Corporate Funding vs. Traditional Venture Capital Investment in Pittsburgh Companies in Autonomous Systems-Related Industry Verticals, 2015-present**

| Discipline Area | Number of Publications, 2016-present | Publications Specialization Index* |
|---|---|---|
| Engineering, Electrical & Electronic | 3,134 | 0.93 |
| Computer Science, Artificial Intelligence | 2,572 | **2.65** |
| Computer Science, Theory & Methods | 2,515 | **1.89** |
| Materials Science, Multidisciplinary | 1,840 | 0.75 |
| Computer Science, Information Systems | 1,550 | **1.44** |
| Computer Science, Interdisciplinary Applications | 1,208 | **1.62** |
| Computer Science, Software Engineering | 1,089 | **2.18** |
| Mathematics, Applied | 741 | **1.20** |
| Computer Science, Hardware & Architecture | 731 | **1.62** |
| Energy & Fuels | 674 | 0.71 |
| Robotics | 655 | **3.01** |
| Telecommunications | 613 | 0.65 |
| Statistics & Probability | 597 | **1.27** |
| Automation & Control Systems | 551 | 1.10 |
| Mathematics | 518 | 0.74 |
| Operations Research & Management Science | 484 | **1.51** |
| Engineering, Mechanical | 463 | 0.63 |
| Computer Science, Cybernetics | 437 | **2.88** |
| Optics | 434 | 0.39 |

**Value >= 1.2 indicates highly specialized publishing activity relative to national trends in this field*

***Source:*** *TEConomy analysis of Clarivate Web of Science publications data*

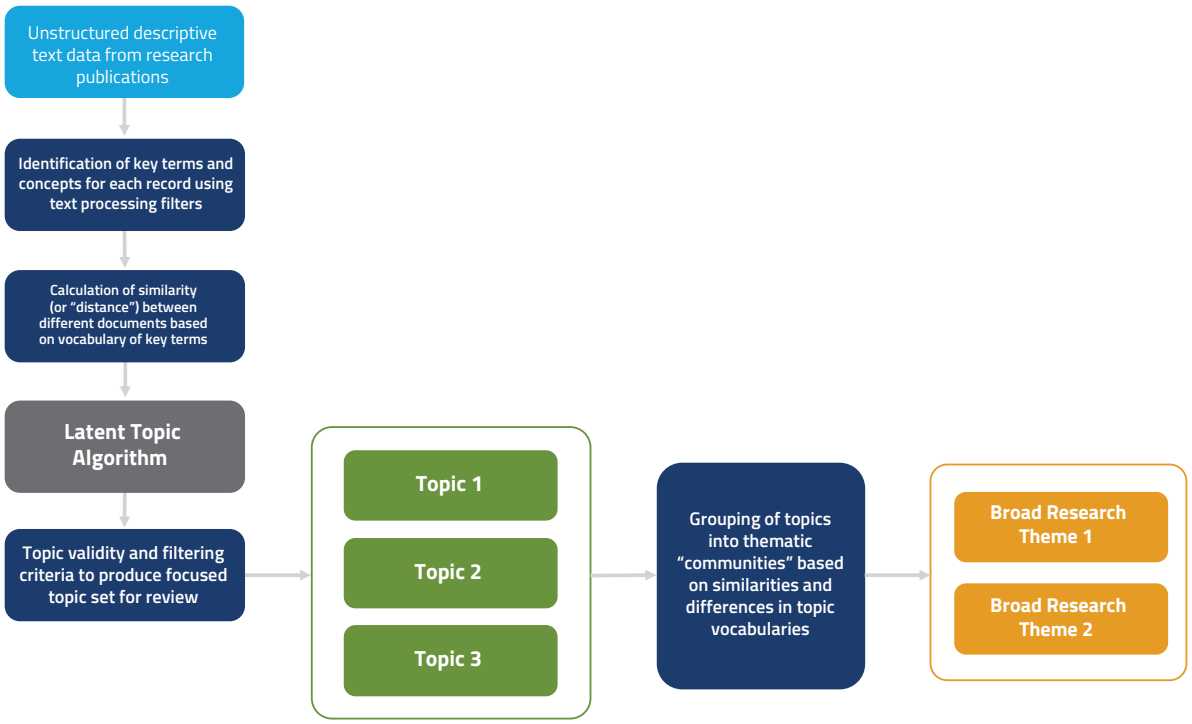
The region shows highly specialized levels of activity in computer science, robotics, and math and statistics research areas, reflecting the presence of leading institutions such as Carnegie Mellon University (CMU) as well as activity in computing and engineering departments at the University of Pittsburgh.

While research disciplines can be illustrative of a region's critical mass in key areas, today's institutional research models emphasize multidisciplinary research that combines the expertise of multiple faculty across multiple research areas to advance translational work, a perspective not easily captured using summary totals shown above. As noted in previous appendices, this context is particularly important to autonomous systems given the way in which they combine systems to enable functionality and leverage cross-cutting technologies that span a variety of applications areas. To examine the

context of research publications activity in further detail to identify cross-cutting thematic areas of focus within publications, TEConomy analyzed the unstructured text content present in publications records.

This type of thematic analysis uses machine learning algorithms to identify topics (or themes) that are "latent" within the underlying vocabulary of a set of text data using a combination of natural language processing (NLP) and unsupervised clustering methods. The descriptive text content from research publications records present in titles, abstracts, and author-generated keyword descriptors was used to form the data set of unstructured text processed by the analysis. As shown in Figure E1 below, this unstructured text is processed by latent topic modeling algorithms to generate detailed underlying thematic areas of focus present in the text content which can then be grouped into broad, higher level research themes.

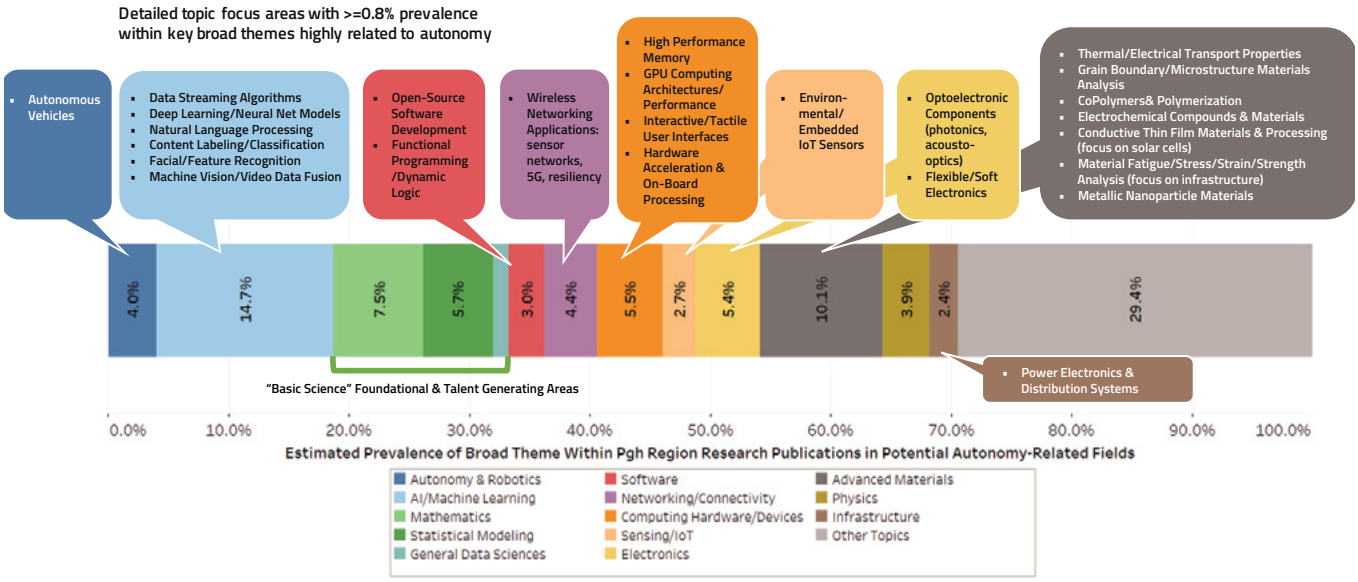
**FIGURE E1.**
**Methodology for Latent Topic Model Analysis of Pittsburgh Research Publications Activity to Understand Thematic Areas of Focus**




The results of the analysis of Pittsburgh's autonomy-related research publications identified 140 topics from the set of potential autonomy-related research publications from regional institutions. Ultimately, 95 topics, representing approximately 71% of the total unstructured text content of publications data in potential autonomy-related research areas, had some relevance or potential supporting role for advancing autonomous systems technologies while the remaining 29% of content was focused on other thematic areas. The topics identified through this analysis, highlighted below in Figure E2, span "basic science" autonomy-enabling capabilities in artificial intelligence and data fusion to applied research in machine vision and edge computing. Most notably, almost 19% of the analyzed research publications content deals directly with autonomy or the AI and machine learning capabilities that directly support its deployment. An additional 15% deal with the foundational "basic science" areas of computing and data sciences in statistics and mathematics that advance machine learning capabilities and develop skilled talent supports growth of a research enterprise. Across the remaining thematic areas, there is still further

additional presence of deep expertise in high performance computing hardware and software engineering competencies that can support deployment of autonomous systems.

**FIGURE E2.**
## Identification of Pittsburgh Institutional Research Competencies Using Latent Topic Modeling and Research Publications Data




***Source:*** *TEConomy analysis of Clarivate Web of Science publications data*

Both the levels of specialization and depth in autonomy-enabling research and technologies outlined above demonstrate a robust set of core competencies aligned with the autonomous systems industry within Pittsburgh's base of research publishing activity. An additional perspective that confirms these findings comes from examination of CS Rankings data, which indexes major computer science publications and ranks institutions based on their activity at the most prestigious computer science conferences. CSRankings documentation notes that the data is intended to rank academic departments by their presence at the most prestigious computer science publication venues as a means of assessing leading research institutions. Research areas included in the rankings data are based on the Association for Computing Machinery (ACM) Special Interest Groups which represent major areas of computer science and are included based on a criteria of having at least 50 R1 institutions with publications in top conferences in that research area over the last 10 years.

The rankings metrics leverage the DBLP computer science bibliography which provides information on major computer science journals and proceedings. DBLP indexes over 4.4 million publications but does not currently index general science journals such as Science, Nature, and PNAS. Thus, this data resource is best viewed as identifying a core set of computer science (CS) research activity indicators and associated faculty who are engaged in various subject matter areas within the discipline. It is selective, and effective at identifying people who are deeply specialized in the discipline, but it is less effective at identifying people at minor institutions or in peripheral (non-CS) areas that may still be engaged in CS research.

As shown below in Tables E2 and E3, amongst all institutions globally CMU is ranked first over the 2015 to 2021 time period in AI-related publishing with 73 publishing authors (by contrast, the next closest U.S. institution in the rankings has 50 publishing authors). In the area of robotics CMU is ranked third globally over the same time period with the highest number of publishing authors (29, the leading institution has 23 publishing authors).

## TABLE E2.
## CSRankings Data for AI* Research Activity, 2015-2021

| Ranking | Institution | Geometric Mean Count of Papers Published, 2015-2021 | Number of Publishing Faculty, 2015-2021 |
|---|---|---|---|
| 1 | Carnegie Mellon University | 70.3 | 73 |
| 2 | Tsinghua University | 55.3 | 87 |
| 3 | Peking University | 53.7 | 97 |
| 4 | Chinese Academy of Sciences | 38.8 | 48 |
| 5 | Stanford University | 37.1 | 50 |
| 6 | Cornell University | 32.4 | 40 |
| 7 | Nanyang Technological University | 30.6 | 37 |
| 8 | Massachusetts Institute of Technology | 30.4 | 57 |
| 9 | Univ. of California - Berkeley | 29 | 53 |
| 10 | University of Maryland - College Park | 28.7 | 40 |

**Defined as including the CSRankings research areas of AI, Computer Vision, and Machine Learning/Data Mining*

***Source:*** *CSRankings*

## TABLE E3.
## CSRankings Data for Robotics Research Activity, 2015-2021

| Ranking | Institution | Geometric Mean Count of Papers Published, 2015-2021 | Number of Publishing Faculty, 2015-2021 |
|---|---|---|---|
| 1 | Univ. of California - Berkeley | 64.9 | 23 |
| 2 | Massachusetts Institute of Technology | 50.8 | 16 |
| 3 | Carnegie Mellon University | 50.2 | 29 |
| 4 | University of Tokyo | 49.8 | 15 |
| 5 | University of Pennsylvania | 49.6 | 16 |
| 6 | TU Munich | 39 | 10 |
| 7 | University of Freiburg | 31.8 | 6 |
| 8 | Stanford University | 29.4 | 12 |
| 9 | Imperial College London | 29.2 | 10 |
| 10 | University of Minnesota | 26.7 | 6 |

***Source:*** *CSRankings*

## Scan of Autonomy-Related Research Grant and Funded Research Activity at Pittsburgh Institutions

In addition to research publications, grant awards and internal R&D funding levels can provide another indicator of activity in enabling capabilities anchored by regional research institutions.

TEConomy conducted a review of recent grant awards to Pittsburgh regional research institutions from 2015 through early 2021 by key federal funding agencies who are most active in autonomous systems research programs including the National Science Foundation (NSF), Department of Defense (DoD), Department of Energy (DoE), and the National Aeronautics and Space Administration (NASA). Table E4 shows the details of autonomy-related grant awards by broad focus area, and indicates high levels of DoD support for capabilities in AI, machine learning, and robotics related to autonomous systems and related mission support. The vast majority of grant recipients were affiliated with CMU and supported both academic research centers as well as individual research projects. Despite lower overall funding levels compared to private investment, the total footprint of grant activity in autonomous systems was significant and totaled almost $163M, representing more than 12% of all grant funding activity to Pittsburgh institutions from these sources over this time period.

**TABLE E4.**
Review of Autonomy-Related Grants Activity at Pittsburgh Institutions by Technology Focus Areas, 2015-early 2021

| Autonomy-Related Grant Focus Area | NSF Grant Awards | NSF Total Grant Dollars ($M) | DOD Grant Awards | DOD Total Grant Dollars ($M) | DOE Grant Awards | DOE Total Grant Dollars ($M) | NASA Grant Awards | NASA Total Grant Dollars ($M) |
|---|---|---|---|---|---|---|---|---|
| AI/Machine Learning | 17 | 9.1 | 18 | 39.1 | | | 1 | 0.5 |
| Computing | 6 | 1.9 | 6 | 7.3 | | | | |
| Cyber/Cyber-Physical Security | 5 | 3.5 | 11 | 15.3 | | | | |
| Hardware | 4 | 3.2 | | | | | | |
| Robotics | 20 | 11.3 | 15 | 47.6 | 1 | 1.2 | 3 | 0.8 |
| Sensing & IoT | 14 | 9.0 | 6 | 2.9 | 1 | 1.5 | | |
| Full Stack Systems | | | | | | | | |
| Aerial | | | 4 | 0.5 | | | | |
| Ground | | | | | 1 | 1.9 | | |
| Marine | | | 3 | 2.6 | 1 | 2.0 | | |
| Space | | | | | | | 6 | 1.7 |
| **Grand Total** | **66** | **38.0** | **63** | **115.3** | **4** | **6.6** | **10** | **3.0** |

***Source:*** *TEConomy analysis of federal grant award data via NSF and USAspending.gov*

Another means of gauging the strength of institutional research enterprises is to examine R&D spending levels. To track academic R&D output, the National Science Foundation conducts its Higher Education Research and Development Survey (HERD). This annual survey captures R&D output by academic discipline for institutions with $150,000 or more in total expenditures. Pittsburgh has two major research universities included in the HERD survey: Carnegie Mellon University (CMU) and the University of Pittsburgh (Pitt).

Detailed R&D expenditures for these two institutions are shown in Table E5. While the data are not collected with the specificity of categories like autonomous vehicles or robotics, the HERD survey does track expenditures across academic disciplines that are relevant to autonomous mobility work, including computer and information sciences and engineering sub-fields. Between 2015 and 2019, CMU spent a sizable $676.2 million in R&D in computer and information sciences as well as $126.0 million in electrical, electronic, and communications engineering. CMU also conducted $279.4 million in other engineering research. While Pitt has a lower overall volume of expenditures, R&D output totaled $156.3 million across the computer science and engineering disciplines. Most notably, CMU's R&D expenditures over the period in computer and information sciences rated 2nd out of all institutions included in HERD data, with nearly 68% of this funding coming from federal government sources.

**TABLE E5.**
## Academic R&D Expenditures by Institution and Field of Study, 2015-19

| Field of Study | Carnegie Mellon University | | University of Pittsburgh | |
|---|---|---|---|---|
| | Total R&D Expenditures ($M) | Ranking Amongst HERD Institutions | Total R&D Expenditures ($M) | Ranking Amongst HERD Institutions |
| Computer and information sciences | $676.2 | 2nd | $43.2 | 63rd |
| Electrical, electronic, and communications engineering | $126.0 | 23rd | $32.3 | 76th |
| Mechanical engineering | $64.8 | 27th | $31.1 | 64th |
| Metallurgical and materials engineering | $45.5 | 28th | | |
| Civil engineering | $30.2 | 68th | $15.1 | 109th |
| Aerospace, aeronautical, and astronautical engineering | $14.7 | 46th | | |
| Industrial and manufacturing engineering | | | $11.1 | 28th |
| Other engineering | $124.1 | 20th | $23.6 | 84th |

***Source:*** *Higher Education Research and Development Survey, NSF; TEConomy analysis.*

## Conclusions from Analyses of Pittsburgh's Research and Innovation Core Competencies Driving Technology Push

As demonstrated by the world leading position of CMU's research enterprise and supplemented by additional regional institutions, there is a critical mass of regional research activity focused around key enabling capabilities of autonomous systems in Pittsburgh. and major companies. The high level of research volume has a distinctive set of thematic focus areas in AI, machine learning, robotics, and other hardware and software applications that directly support autonomous systems innovation. The presence of additional grant and center activity at research institutions also supports the creation of new autonomy-related technologies and applications which supplements the regional technology push in these areas.

In addition to being anchored by world class research institutions and local companies, there are also significant multinational companies with site locations in the Pittsburgh region focused on R&D and innovation that contribute to the region's technology push. Several of these key industry centers include:

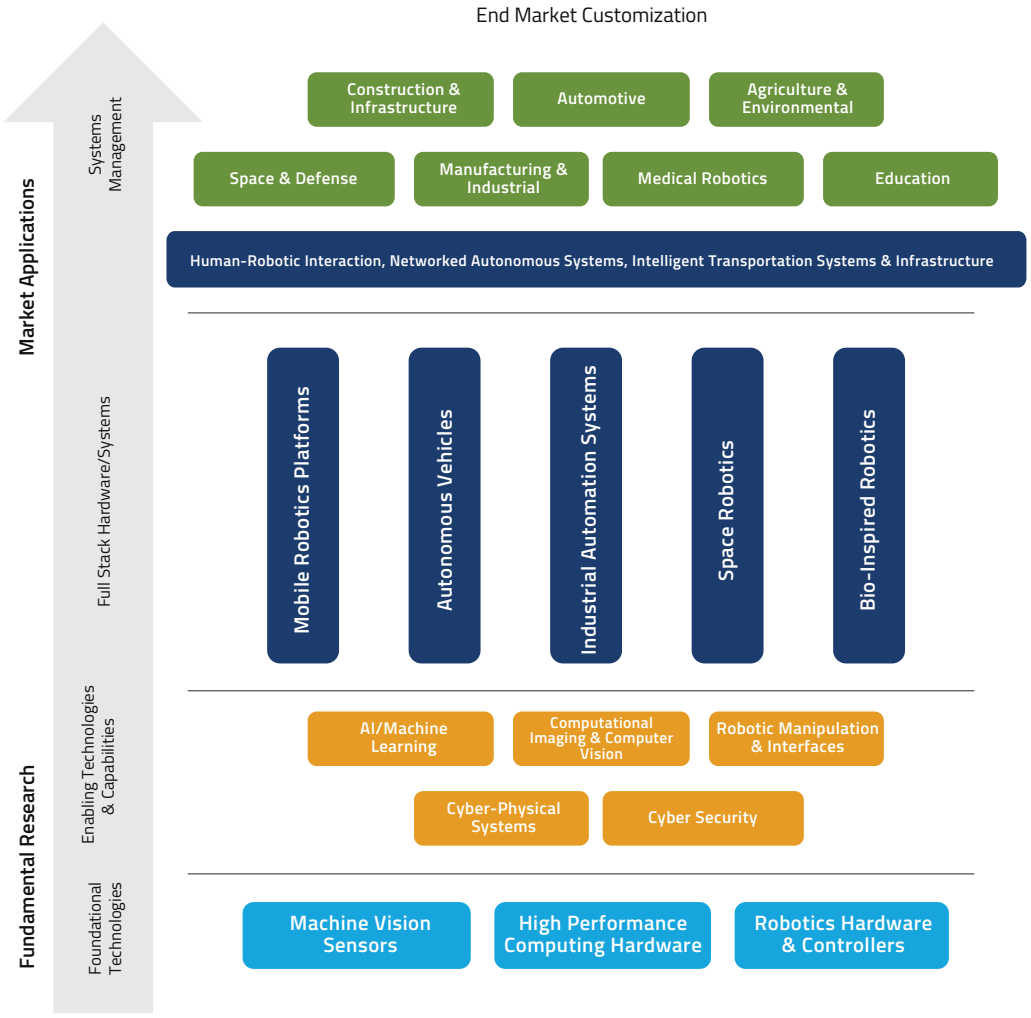
- Aptiv Technologies' Pittsburgh Technology Center, which houses robotics engineers that are focused on autonomous vehicles software and systems solutions innovation.
- Caterpillar's Pittsburgh Automation Center, which is focused on development and testing of off-road vehicles and equipment enabled by data processing from sensor technology
- General Dynamics' Viz Center of Excellence, which takes a human-centric design approach to develop software for visual analytics, decision support, collaboration, augmented and virtual reality
- Honeywell's Robotics Tech Center, focused on innovating and developing artificial intelligence, machine learning, computer vision and advanced robotics for use across supply chains
- Robert Bosch's Research and Technology Center, focused on IoT and automation technologies innovation in software, security technologies, and integration of solutions into business processes
- Siemens' Rail Automation Facility, focused on computer and automation systems for rail facilities, commuter rail, and train control systems
- Denso Pittsburgh Innovation Lab, which conducts research aimed at achieving Level-4 automated driving solutions
- General Motors-CMU Collaborative Research Labs in vehicle information technology and autonomous driving

It is difficult to quantitatively analyze the innovation output of these industry R&D and technology centers, but their presence in the regional ecosystem serves as an indicator of the deep level of core competencies displayed across fundamental technology areas in autonomous systems applications.

Figure E3 below summarizes Pittsburgh's areas of autonomy-related technology core competencies, as outlined by the set of quantitative analyses of research activity above, within the context of the autonomy technology stack. Note that this does not represent a complete view of Pittsburgh's activity or competencies, but rather the perspective given by research activity indicators across regional institutions.

**FIGURE E3.**

## Pittsburgh's Research and Innovation-Driven Technology Core Competencies Shown Within the Context of the Autonomous Systems Technology Stack



# Appendix F:
## Profile of Pittsburgh's Autonomy-Enabling Talent Base

Generating and maintaining a skilled talent base represents one of the key competitive advantages that enables long term success in any industry that relies on digital technologies. Pittsburgh's skilled talent base that provides the workforce for the regional autonomous systems industry to draw on is a key asset, and the profile of this workforce highlights any competitive advantages or gaps in talent supply for the region.

Given the cross-disciplinary nature of skills and business experience in autonomous systems, it is difficult to establish a definitive subset of employment working in the technology space using standard occupational classifications. Instead, TEConomy identified the "autonomy-enabling" workforce by starting with a focus on labor segments that contribute key skill sets that have the potential to be leveraged by industry to drive solutions as part of autonomous systems development. Using the federal Standard Occupation Classification (SOC) system, TEConomy constructed a definition of autonomy-enabling workforce segments for profiling Pittsburgh's talent base as seen below in Table F1.

**TABLE F1.**
**Definition of Autonomy-Enabling Workforce Segments Used in TEConomy Analysis of Pittsburgh Talent Base**

| Autonomy-Enabling Workforce Segment | Number of SOC Codes in Segment | Examples of Occupations in Segment |
|---|---|---|
| Computing & IT | 12 | Software Developers & Software QA Analysts & Testers, Computer Systems Analysts |
| Engineering | 16 | Mechanical Engineers, Electrical Engineers, Industrial Engineers |
| Technicians | 7 | Electro-Mechanical & Mechatronics Technologists & Technicians, Industrial Engineering Technologists & Technicians |
| Mathematics & Statistics | 4 | Data Scientists & Mathematical Science Occupations, Operations Research Analysts |
| Scientists | 4 | Physicists, Materials Scientists |
| Mapping & Geolocation | 3 | Cartographers & Photogrammetrists, Surveying & Mapping Technicians |

## Overall Trends in Pittsburgh's Autonomy-Enabling Workforce

TEConomy leveraged occupational employment data from EMSI, which leverages data from the U.S. Bureau of Labor Statistics, to examine workforce trends across the region (as defined by the 7-county Greater Pittsburgh MSA) over the 2010 to 2020 time period. As shown in Table F2, while Pittsburgh's autonomy-enabling occupational workforce has grown by almost 15% since 2010, more recent growth over the 2015-2020 time period has stalled (1.3% employment growth). Over the last 5 years the state and the country have outpaced the region in growth of this workforce, and a potential area of concern is the computing & IT workforce which has remained steady while state and national growth trends have continued. The region does display high specializations in engineering, technician, and math and statistics occupations (20%, 39%, and 20% more concentrated regionally than in the national workforce mix respectively), but growth in overall engineering employment also significantly lags the state and country over the last five years.

**TABLE F2.**
## Summary Trends in Greater Pittsburgh's Autonomy-Enabling Workforce, 2010-2020

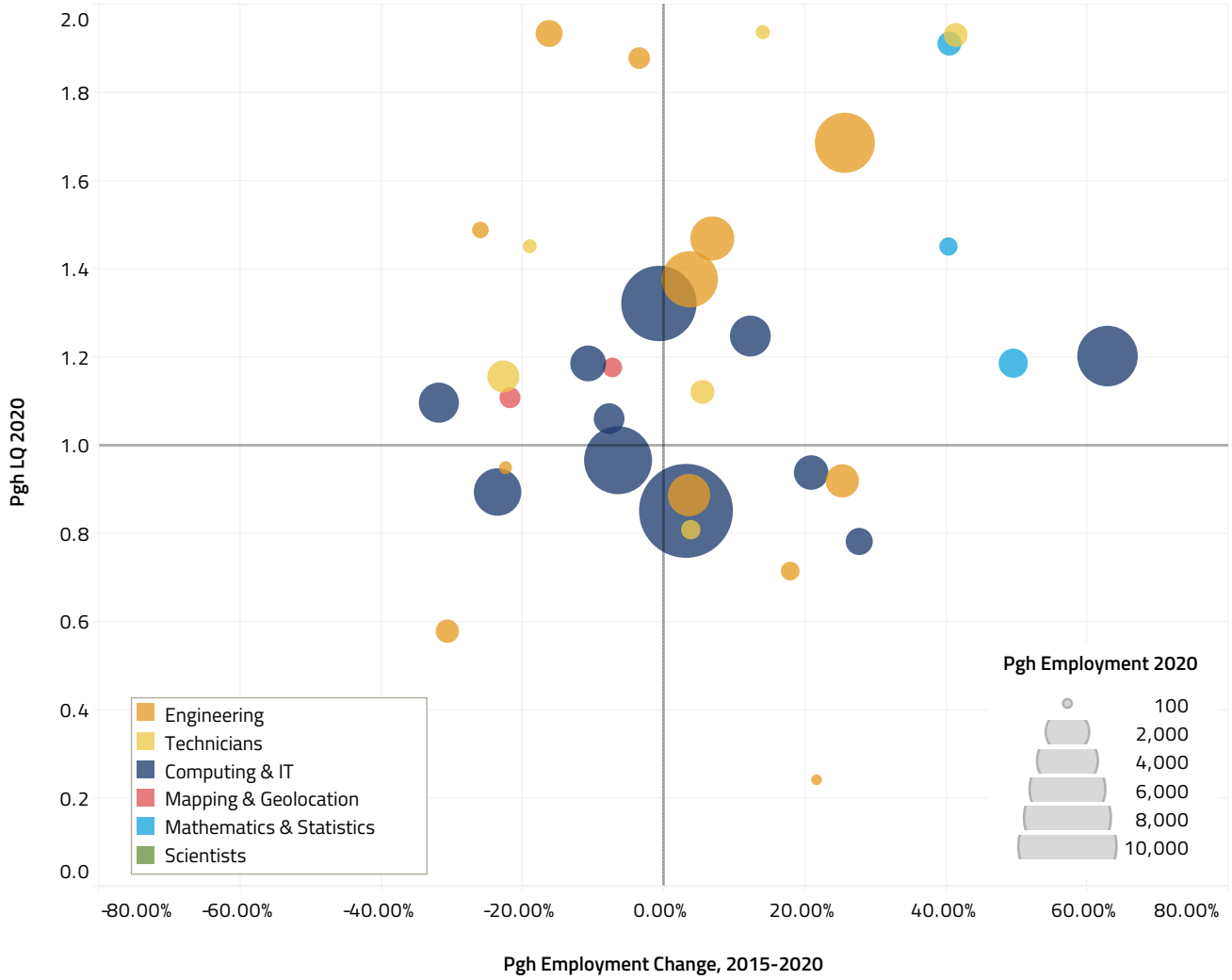
| Autonomy-Enabling Occupation Category | Pittsburgh Region Jobs, 2010 | Pittsburgh Region Jobs, 2015 | Pittsburgh Region Jobs, 2020 | Pittsburgh Region Growth, 2015-2020 | PA Growth, 2015-2020 | US Growth, 2015-2020 | 2020 Specialization |
|---|---|---|---|---|---|---|---|
| Computing & IT | 29,154 | 34,813 | 35,124 | 0.9% | 5.8% | 12.0% | 1.01 |
| Engineering | 15,221 | 15,662 | 15,715 | 0.3% | 8.1% | 8.2% | 1.20 |
| Mapping & Geolocation | 1,059 | 1,102 | 934 | -15.3% | -5.5% | 0.6% | 1.06 |
| Mathematics & Statistics | 624 | 1,331 | 1,907 | 43.3% | 33.7% | 16.0% | 1.39 |
| Scientists | 265 | 309 | 363 | 17.4% | 28.4% | 2.2% | 0.84 |
| Technicians | 3,615 | 3,329 | 3,220 | -3.3% | -12.1% | -3.8% | 1.20 |
| Total, all Autonomy-Enabling Occupations | 49,938 | 56,547 | 57,263 | 1.3% | 6.0% | 9.9% | 1.08 |
| Total, all Occupations | 1,198,217 | 1,223,412 | 1,201,539 | -1.8% | 6.0% | 9.9% | |

***Source:*** *TEConomy analysis of occupational data from Emsi (Emsi Release 2021.1)*

A more detailed profile of specific occupations within these segments with 100 or more employees in the Pittsburgh region in 2020 in shown below in Figure F1, which combines recent growth and specialization perspectives. Occupations that represent specializations for the region (i.e. are more concentrated in the employment base of the Pittsburgh region relative to occupational employment patterns observed across the entire U.S. workforce, represented by a location quotient > 1.0) as well as have strong growth trajectories over the last five years (i.e. those occupations located in the upper right quadrant of Figure x) are particularly important to the region as potential competitive advantages. The profile shown below points to several ongoing regional trends in autonomy-enabling occupations:

- Occupations in computing and IT segments with large regional employment footprints tended to be lower growth from 2015-2020. One exception to this trend was standout growth in the detailed occupation representing All Other Computer Occupations, which includes labor categories not captured under other computing and IT categories such as information security engineers, network engineers, systems architects, GIS technologists and technicians, and web administrators.
- Key occupations that were both highly specialized and growing within the regional engineering workforce included mechanical engineers and mechanical engineering technicians.
- Occupations that currently have small employment footprints, but are highly specialized and growing over the last five years are focused in statistics and data-related occupations such as statisticians, operations research specialists, and data scientists.

**FIGURE F1.**
Detailed Occupational Profile for Pittsburgh Region Autonomy-Enabling Occupations*, 2015-2020

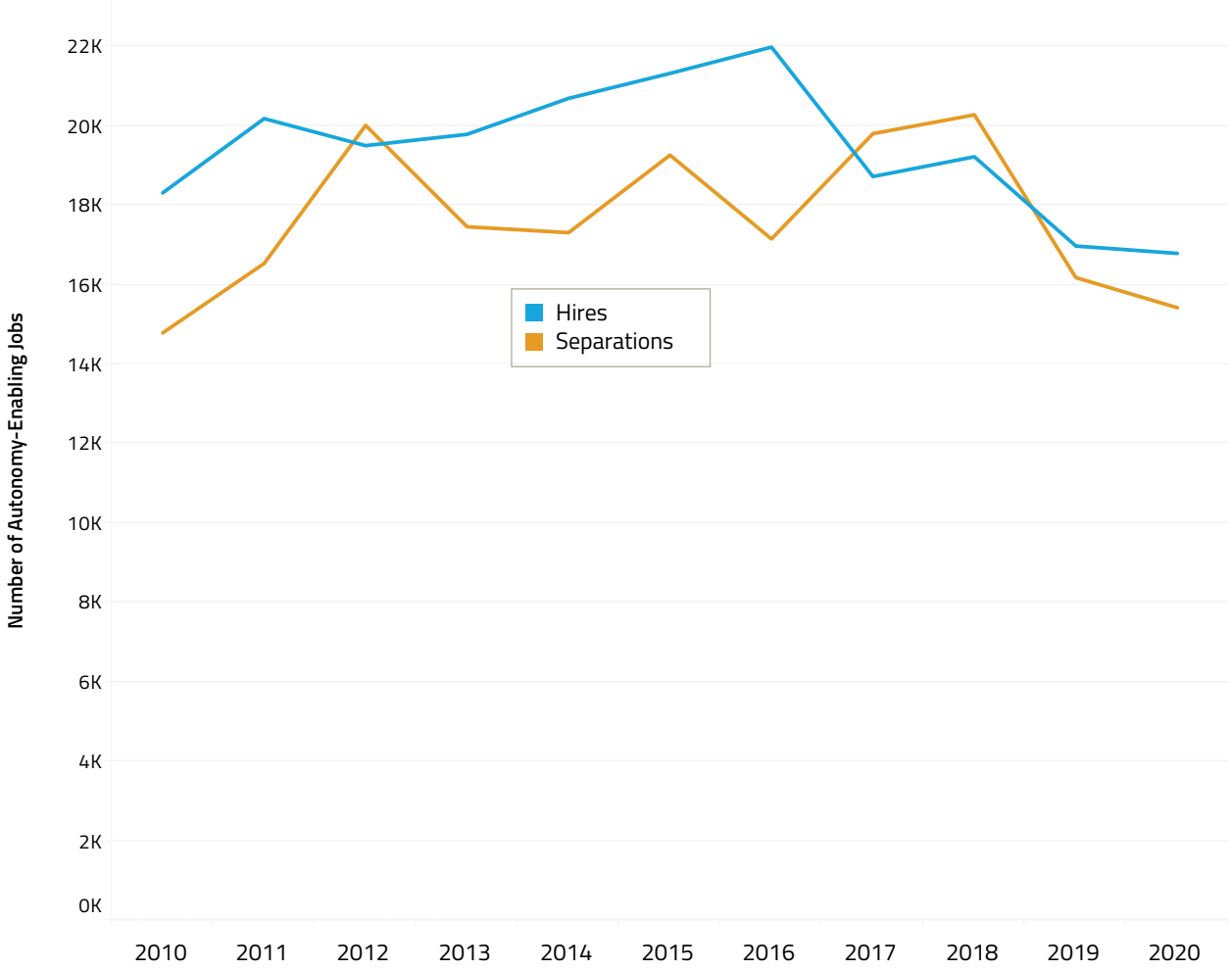



*Includes detailed occupations with 100 or more regional employees in 2020*

***Source:*** *TEConomy analysis of occupational data from Emsi (Emsi Release 2021.1)*

One potential reason for the lower growth rates observed across several large computing and IT workforce segments may be increased labor market churn. Seen in Figure F2, the volatility in annual hires and separations trends since 2010 has been driven mostly by the computing & IT workforce segment which represents over half of all hiring and separation activity across all autonomy-enabling occupational segments. There has been some falloff in labor market movement in autonomy-related occupations since 2018, which is potentially a concern for regional workforce outlook and companies in the autonomous systems industry seeking to expand their local employment footprint. This slowdown in activity may reflect the increasingly competitive regional environment, where skilled talent is increasingly aggressively recruited from a supply that has not grown as quickly as demand.

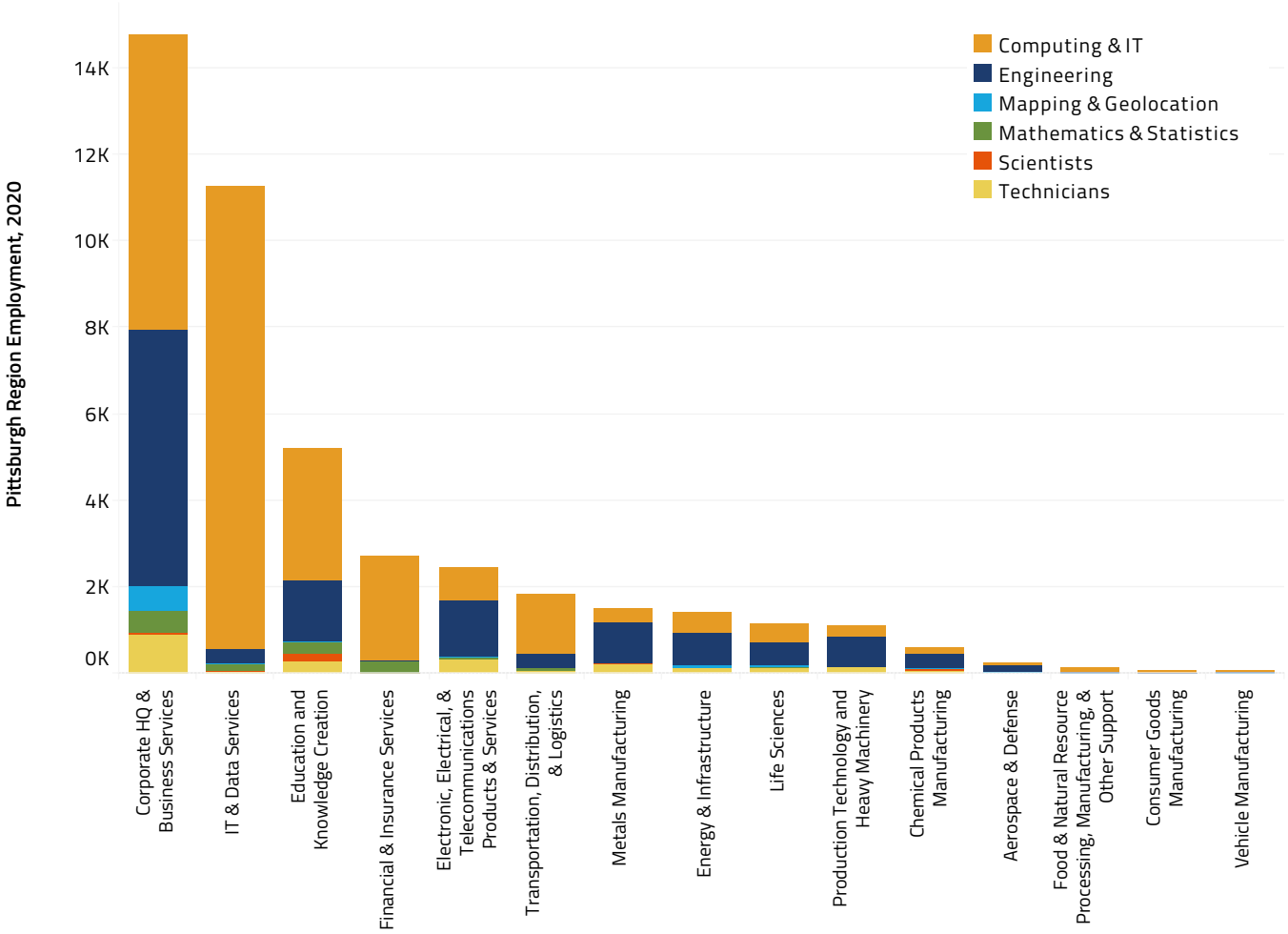
**FIGURE F2.**
Pittsburgh Region Hires and Separations in Autonomy-Enabling Occupations, 2010-2020




***Source:*** *TEConomy analysis of occupational data from Emsi (Emsi Release 2021.1)*

Major regional industry clusters where autonomy-enabling talent is employed are shown in Figure F3 and confirm the importance of the computing and IT workforce segment in driving broader workforce patterns. In 2020, autonomy-enabling occupations in Pittsburgh tended to be overwhelmingly concentrated in corporate and business services operations as well as IT & data services industries, the latter of which is where many major autonomous vehicles companies are classified (as well as the majority of other regional "tech" companies). In contrast to the computing and IT workforce segment, engineering services firms with a focus outside of or broader than technology sectors tended to be the primary employers of engineering segments of the regional workforce.

**FIGURE F3.**
Major Industry Cluster Employment of Pittsburgh Autonomy-Related Occupations, 2020




***Source:*** *TEConomy analysis of occupational data from Emsi (Emsi Release 2021.1)*

## Trends in Autonomy-Related Job Postings in the Pittsburgh Region

Within the broader autonomy-enabling context, workforce trends can also be examined through the lens of job postings that highlight key autonomy-related skills to help gauge current activity and industry demand. This approach provides a more detailed look at regional autonomy workforce activity using skills-based criteria rather than broad industry or occupational codes and can give insights into the dynamics driving hiring by regional employers seeking specific types of talent.

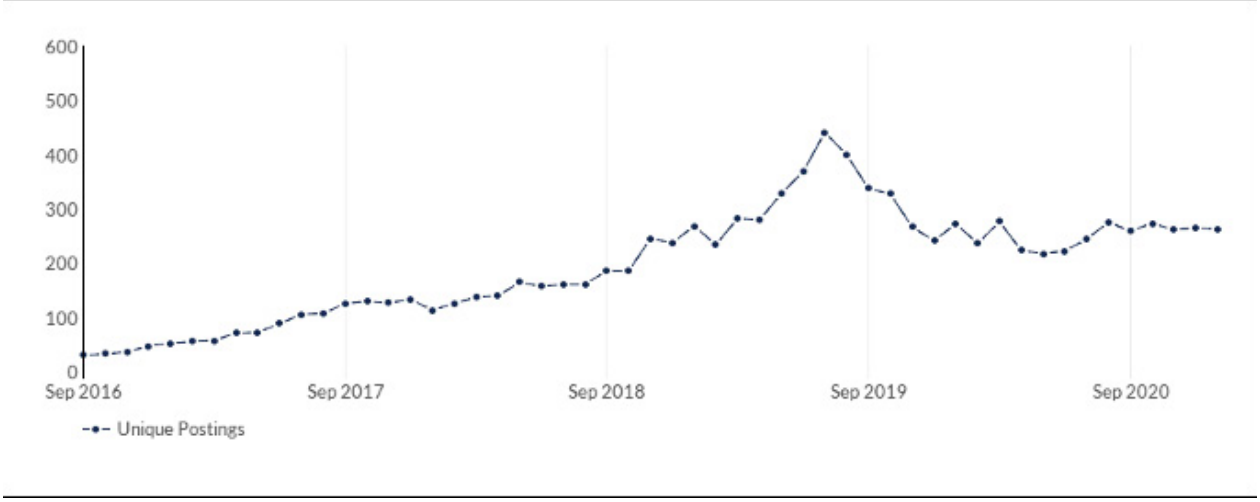
To analyze Pittsburgh's autonomy-related job demand, TEConomy leveraged the EMSI Job Posting Analytics database, a service that aggregates cross-listed job postings across a number of job search websites and state agencies to identify unique positions and descriptive data outlining the characteristics of the advertised positions. Data on postings activity used in this analysis covered the September 2016 through January 2021 time period and included all listings advertising positions located in the Pittsburgh MSA.

To identify autonomy-related positions, TEConomy developed a set of target skills specifically related to autonomous systems, mobile robotics, machine vision and perception, and other key areas of the autonomous systems technology stack. This set of

skills included any mention of a variety of full stack autonomous systems applications (air, land, marine, and others) within the body of the job posting as well as any mentions of competencies in mobile robotics, robotic navigation, machine or computer vision, and other relevant autonomous systems skill sets.

Ultimately, the analysis identified 3,214 unique job postings with highly relevant autonomous systems context or skills for jobs in the Pittsburgh region over the May 2016 to January 2021 time period. For context, this represents 2% of all national job postings activity over the time period in autonomy-related skills; however, Pittsburgh is ranked as 3rd most active city in the U.S. in postings over the time period. As shown in Figure F4 below, job postings activity in the region peaked in July of 2019 and has remained steady at somewhat lower levels since.

**FIGURE F4.**
**Job Postings Activity for Autonomy-Related Positions in the Pittsburgh Region, September 2016-January 2021**




***Source:*** *TEConomy analysis of job postings data from Emsi (Emsi Release 2021.1)*

Leading job titles mentioned in Pittsburgh autonomy-related job postings with at least 25 unique postings over the period are shown below in Table F3. Job titles indicate the outsized importance of the systems engineering and software development workforce to the regional autonomous systems industry driving industry demand for skilled talent.

**TABLE F3.**
## Leading Job Titles in Job Postings Activity for Autonomy-Related Positions in the Pittsburgh Region, September 2016-January 2021

| Posted Job Title | Unique Postings (Sep 2016 - Jan 2021) | Median Posting Duration |
|---|---|---|
| Robotics Engineers | 198 | 54 days |
| Robotics Software Engineers | 185 | 45 days |
| Software Engineers | 133 | 43 days |
| Senior Software Engineers | 84 | 45 days |
| Electrical Engineers | 59 | 37 days |
| Vehicle Engineers | 53 | 49 days |
| Autonomy Engineers | 52 | 42 days |
| Controls Engineers | 45 | 43 days |
| Infrastructure Software Engineers | 41 | 27 days |
| Embedded Software Engineers | 35 | 46 days |
| Machine Learning Engineers | 34 | 34 days |
| Mechanical Engineers | 30 | 36 days |
| Automation Engineers | 29 | 32 days |
| System Safety Engineers | 28 | 58 days |
| Simulation Software Engineers | 27 | 42 days |
| Solution Architects | 27 | 5 days |
| Innovation Engineers | 26 | 10 days |
| Simulation Engineers | 26 | 60 days |

***Source:*** *TEConomy analysis of job postings data from Emsi (Emsi Release 2021.1)*

Key regional companies generating postings activity that require autonomous systems skills are shown below in Table F4. High postings activity on the part of autonomous vehicles companies can be observed, although mid-size custom robotics companies are also consistently searching for hires as well.

**TABLE F4.**
## Leading Companies Generating Job Postings Activity for Autonomy-Related Positions in the Pittsburgh Region, September 2016-January 2021

| Company | Company Focus | Unique Postings (Sep 2016 - Jan 2021) | Median Posting Duration |
|---|---|---|---|
| Argo AI | Autonomous vehicles | 283 | 35 days |
| Uber Technologies, Inc. | Autonomous vehicles | 245 | 60 days |
| Aptiv PLC | Autonomous vehicles | 175 | 44 days |
| Carnegie Mellon University | Research university | 171 | 69 days |
| CyberCoders, Inc. | Staffing & recruitment | 106 | 45 days |
| Honeywell International Inc. | Multinational product company | 72 | 72 days |
| Seegrid Corporation | Automation solutions company | 71 | 29 days |
| Aerotek, Inc. | Staffing & recruitment | 65 | 17 days |
| Omnicell, Inc. | Pharmacy automation | 61 | 35 days |
| Aurora | Autonomous vehicles | 57 | 56 days |
| Smith & Nephew PLC | Medical robotics | 57 | 57 days |
| Delphi Automotive PLC | Automotive systems | 52 | 63 days |
| Caterpillar Inc. | Machinery & engines | 47 | 44 days |
| Innovation Works, Inc. | Startup accelerator and seed investor | 47 | 78 days |
| Berkshire Grey, Inc. | Retail fulfillment automation | 37 | 21 days |
| Iam Robotics, LLC | Autonomous mobile picking robots | 35 | 37 days |
| Neya Systems, LLC | Unmanned systems | 34 | 38 days |
| Kennametal Inc. | Tooling & industrial materials | 26 | 60 days |
| Ansys, Inc. | Engineering simulation software | 26 | 58 days |
| Bossa Nova Robotics Inc | Autonomous service robots | 25 | 64 days |

***Source:*** *TEConomy analysis of job postings data from Emsi (Emsi Release 2021.1)*

As noted above, mentions of key autonomy-related skills were used to identify the set of postings with high relevance to autonomous systems. As shown in Table F5, the other types of required skills listed in these job postings demonstrate the importance of software expertise that is needed to complement engineering and hardware skills in autonomous systems applications.

**TABLE F5.**

## Top Required Skills Listed in Job Postings Activity for Autonomy-Related Positions in the Pittsburgh Region, September 2016-January 2021

| Required Skill | Frequency in Postings |
|---|---|
| Robotics | 53% |
| C++ (Programming Language) | 39% |
| Automation | 37% |
| Software Engineering | 33% |
| Python (Programming Language) | 32% |
| Computer Science | 30% |
| Autonomous Vehicles | 30% |
| Linux | 29% |
| Electrical Engineering | 25% |
| Algorithms | 25% |
| Machine Learning | 21% |
| Software Development | 21% |
| Computer Engineering | 20% |
| Computer Vision | 19% |
| C (Programming Language) | 18% |
| Robot Operating Systems | 15% |
| Mechanical Engineering | 15% |
| Debugging | 14% |
| MATLAB | 12% |
| Systems Engineering | 12% |
| Prototyping | 11% |
| Light Detection And Ranging (LiDAR) | 10% |
| Motion Planning | 10% |
| Simulations | 10% |

***Source:*** *TEConomy analysis of job postings data from Emsi (Emsi Release 2021.1)*

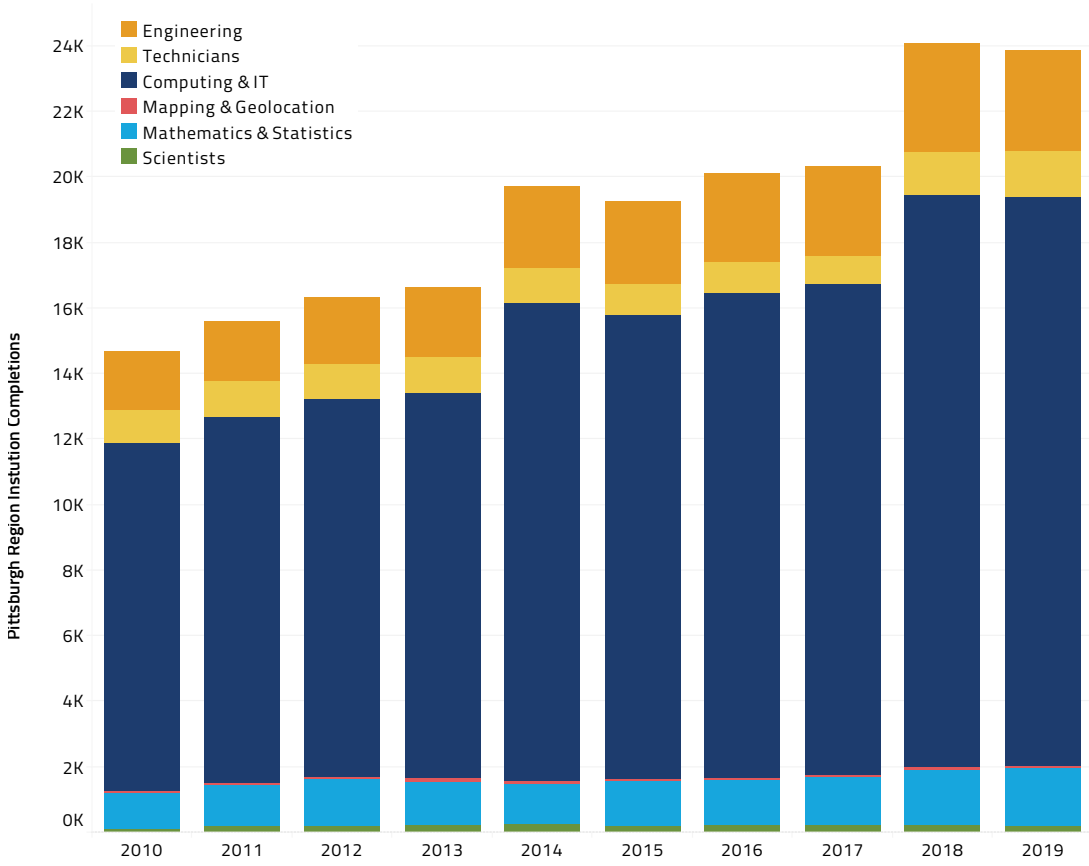
## Context of Autonomy-Enabling Talent Supply for the Pittsburgh Region

Although the analysis of Pittsburgh's autonomy-enabling workforce focuses more on its current composition and demand given the need to attract talent from a broader global base to serve the emerging industry, TEConomy also profiled the autonomy-enabling talent supply generated by the academic institutions of the region. The deep research excellence and core competencies in autonomous systems outlined in Appendix E make it clear that the region has a large academic research enterprise engaged in activities aligned with the autonomous systems industry, so understanding the quantity of graduates being produced is important to broader considerations of the balance of talent supply and demand.

Data from the U.S. Department of Education's Integrated Postsecondary Education Data System (IPEDS), a system of surveys examining postsecondary education institutions and their characteristics, was used to examine degree program completions for the Pittsburgh region. Leveraging a crosswalk linking degree program codes to occupations produced by the National Center for Education Statistics (NCES), it is possible to examine the high level talent supply being generated in Pittsburgh region from academic institutions that maps completions to the occupations that make up the autonomy-enabling workforce outlined above. As shown in FigureF5, the number of regional degree program completions aligned with autonomy-enabling occupations in the Pittsburgh region has steadily risen over time from 14.7k in 2010 to 23.9k in 2019. The vast majority of these completions are aligned with occupations in the computing and IT occupational segment, which has risen in volume to over 17k completions in 2019.

**FIGURE F5.**

**Degree Program Completions from Pittsburgh Regional Institutions Aligned with Autonomy-Enabling Workforce Segments, 2010-2019**




***Source:*** *IPEDS, NCES CIP-SOC Crosswalk with EMSI modifications, TEConomy analysis*

At first glance, the region appears to be generating excess supply relative to demand from hires examined in job postings, indicating the region potentially has room to grow its autonomy-related workforce without importing talent from outside the region. However, further discussions with academic and industry stakeholders in the region have clarified that the available talent supply volume is not as robust as completions may indicate for several reasons. First, highly skilled graduates, particularly from CMU's graduate level programs, are aggressively recruited by a global audience which impacts the region's retention levels of key portions of the enabling talent base. Second, the overall university footprint for CMU may be somewhat rate limited by geographic and administrative constraints and is not likely to rapidly expand in size at a rate that matches recent observed industry growth. This makes it important to align the additional volume of graduates from other regional programs in computing and IT to the autonomous systems opportunity in order to build out a more robust pipeline that can meet industry demand.

## Conclusions from Analyses of Pittsburgh's Autonomy-Enabling Talent Base

Analysis of workforce trends for the Pittsburgh region clearly indicate the presence of a sizeable base of autonomy-enabling talent that includes a large computing & IT workforce and a specialized engineering and technician workforce. However, neither of these segments have kept pace with state or U.S. growth trends over the past five years, let alone the rapid pace of growth within the national autonomous systems industry itself. The overall falloff in hiring activity over the past five years combined with a high concentration of workforce within corporate and business services industry may indicate a vulnerability to "hollowing out" of the talent needed to support autonomous systems growth, particularly if talent is not connected with the opportunity in a broader way.

Job postings activity in the region seeking specialized autonomy skill sets represents 2% of all national job postings activity in recent years, with Pittsburgh is ranked as 3rd most active city in the U.S. in postings. This is evidence that the region is generating workforce demand at levels that indicate a growing industry cluster with the potential to expand. The position titles and required skill sets within postings activity emphasize the importance of multidisciplinary embedded systems skills to the autonomy industry that combine engineering and design background with expertise in software and machine learning. Cross-disciplinary talent that has this profile is relatively rare, and the region can build a competitive edge in supporting the autonomous industry's growth that can lead to positive externalities for other technology-based sectors.

While an initial scan of talent supply from regional institutions suggests that the region appears to be generating excess supply relative to current demand from hires, the situation in the region is more complicated. Due to intense competition for talent, both from external audiences as well as internally to the region, there are some pressures that keep talent generation more rate-limited at present and require strategic thinking to explore ways to expand the pipeline of autonomy-aligned skill sets.

# Appendix G:
## Profile of The National Autonomous Mobile Systems Industry

Another way of assessing Pittsburgh's competitive position in industry footprint is by benchmarking the volume of autonomous mobility-related companies against cities across the U.S. Because there is no such data source available to analyze industry concentration as it is defined in this report, TEConomy developed a proprietary database of autonomous mobility-related companies of autonomous mobility-related companies with their locations and the product or service that they provide.

## Building the Database

The national database was compiled using data from a variety of sources, including the following:

- **Market research reports**
  Market research reports in relevant technology areas from BCC Research and IBISWorld usually contain reference to leading companies in their respective spaces. These industry areas included the major systems and components that comprise autonomous mobility work, including hardware and sensors, artificial intelligence and machine learning, and advanced vehicle technologies, among others. For additional specialized intelligence related to autonomous mobility, insights were gleaned from a variety of industry landscape graphics that focused on autonomous vehicle and robotics verticals.

- **PitchBook venture capital database**
  The primary source of information on nascent and emerging companies is PitchBook, a leading provider of information on capital markets and investment activity. Targeted searches of key industry areas were performed, including industry verticals such as Autonomous Cars and Robotics and Drones as well as other associated technology areas.

- **SBIR/STTR award database**
  Another source of information used to capture nascent and emerging companies was the database of companies awarded federal Small Business Innovation Research or Small Business Technology Transfer awards. Award titles and descriptions were evaluated for evidence of relevant R&D activity.

- **Association for Unmanned Vehicle Systems (AUVSI) databases**
  AUVSI is a non-profit organization that supports the unmanned systems and robotics industries. AUVSI maintains three international databases that track companies involved in unmanned air, ground, and marine systems. These companies range from major multinational corporations to small and young firms.

- **News articles and other market intelligence**
  Recently published articles from Wired.com and other sites were among the variety of additional sources used to collect information.

The combined dataset produced from these sources totaled several thousand unique entries. Every effort was taken to ensure that companies included in the final database are still in operation and located in the U.S. To capture the scale of autonomous mobility-related activity, a count of establishments was utilized. The database includes all U.S. locations found for companies identified from the data sources listed above. This list of establishments was curated to emphasize autonomous mobility systems and subsystems, including full-stack platforms and major hardware and software components. To that end, each establishment was assigned an industry affiliation based on primary product or service offered.

To evaluate how industry concentration varies by region, TEConomy summed the establishments by Combined Statistical Area (CSA). A CSA is defined by the U.S. Office of Management and Budget (OMB) as a combination of a Metropolitan Statistical Areas (MSAs) and Micropolitan Statistical Areas (μSA) that share economic ties and commuting patterns. The CSA concept was chosen over the use of MSAs due to the nature of some of the industry hubs – places like Detroit and Ann Arbor, while comprising separate MSAs, are better represented as a single geographic unit using the CSA definition which combines them into one region.

Because accurate employment and sales data are not available for all companies, the concentration of autonomous mobility-related activity in each city is defined as the number of relevant establishments by Combined Statistical Area (CSA). TEConomy calculated an additional measure of industrial concentration by tagging major multinationals and other leading companies located in the top CSAs. This "leading company" context was created through qualitative review of market research reports, news articles, and additional intelligence gathered during the process to identify companies with leading market share or other high profile market activity.

While the database has been constructed as thoroughly as possible, there are two main caveats guiding discussion of the findings. First is the difficulty of capturing a snapshot of an industry that is experiencing rapid growth in both established and new areas. Change in these technology areas occurs quickly, with major data sources unable to track company creation and dissolution as quickly as they occur. Second is that the accuracy of the data are limited by the quality of available data sources. Though most entries in the database received some amount of firsthand evaluation by TEConomy, some details gleaned from third-party databases are likely to be inaccurate. Despite these limitations, the database is comprehensive in its coverage of the industry and as exhaustive as possible in compiling companies with relevant technological work.

## Evaluating Pittsburgh's Position in the Industry

The full database of autonomous mobility-related companies is comprised of 1,848 establishments. Pittsburgh ranks seventh in this list with 60 establishments (Table G1) out of a total of 92 Combined Statistical Areas (CSAs) in the database with at least one establishment. While companies working in autonomous mobility are primarily located in the Bay Area and Boston, a handful of other cities have a similar level of activity as Pittsburgh, such as Denver and the D.C./Baltimore area. All CSAs present in the database are mapped in Figure G1.

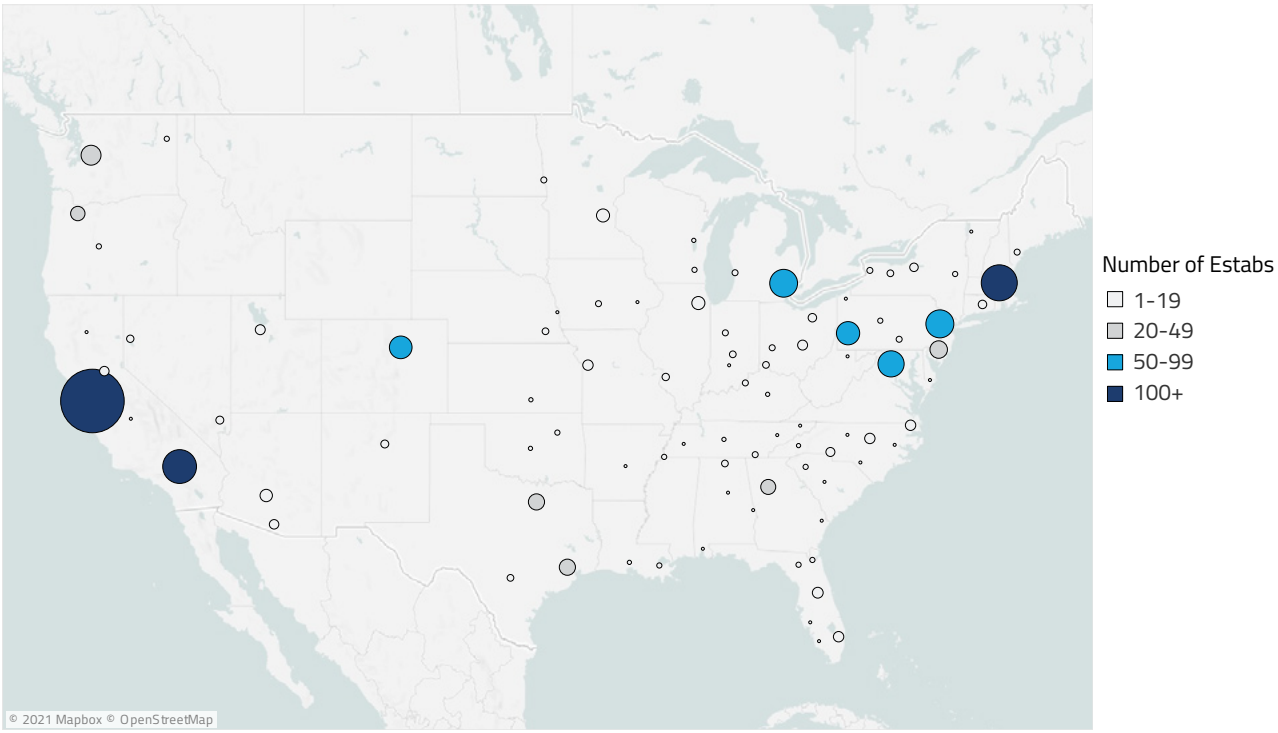
**TABLE G1.**
**Top U.S. Regions by Number of Autonomous Mobile Systems Establishments**

| Region (Combined Statistical Areas) | # of Establishments | % of U.S. Total | Est. % Major Multinationals or Significant Co's |
|---|---|---|---|
| San Jose-San Francisco-Oakland, CA | 449 | 24.3% | 11.8% |
| Boston-Worcester-Providence, MA-RI-NH-CT | 144 | 7.8% | 18.8% |
| Los Angeles-Long Beach, CA | 127 | 6.9% | 14.2% |
| New York-Newark, NY-NJ-CT-PA | 87 | 4.7% | 9.2% |
| Detroit-Warren-Ann Arbor, MI | 86 | 4.7% | 48.8% |
| Washington-Baltimore-Arlington, DC-MD-VA-WV-PA | 76 | 4.1% | 22.4% |
| Pittsburgh-New Castle-Weirton, PA-OH-WV | 60 | 3.2% | 38.3% |

| Region (Combined Statistical Areas) | # of Establishments | % of U.S. Total | Est. % Major Multinationals or Significant Co's |
|---|---|---|---|
| Denver-Aurora, CO | 57 | 3.1% | 15.8% |
| Seattle-Tacoma, WA | 44 | 2.4% | 20.5% |
| Philadelphia-Reading-Camden, PA-NJ-DE-MD | 34 | 1.8% | 11.8% |
| Dallas-Fort Worth, TX-OK | 29 | 1.6% | 24.1% |
| Houston-The Woodlands, TX | 29 | 1.6% | 17.2% |
| Atlanta--Athens-Clarke County--Sandy Springs, GA-AL | 25 | 1.4% | 36.0% |
| Portland-Vancouver-Salem, OR-WA | 23 | 1.2% | 4.3% |

***Source:*** *TEConomy analysis of custom database of U.S. autonomous mobile systems companies*

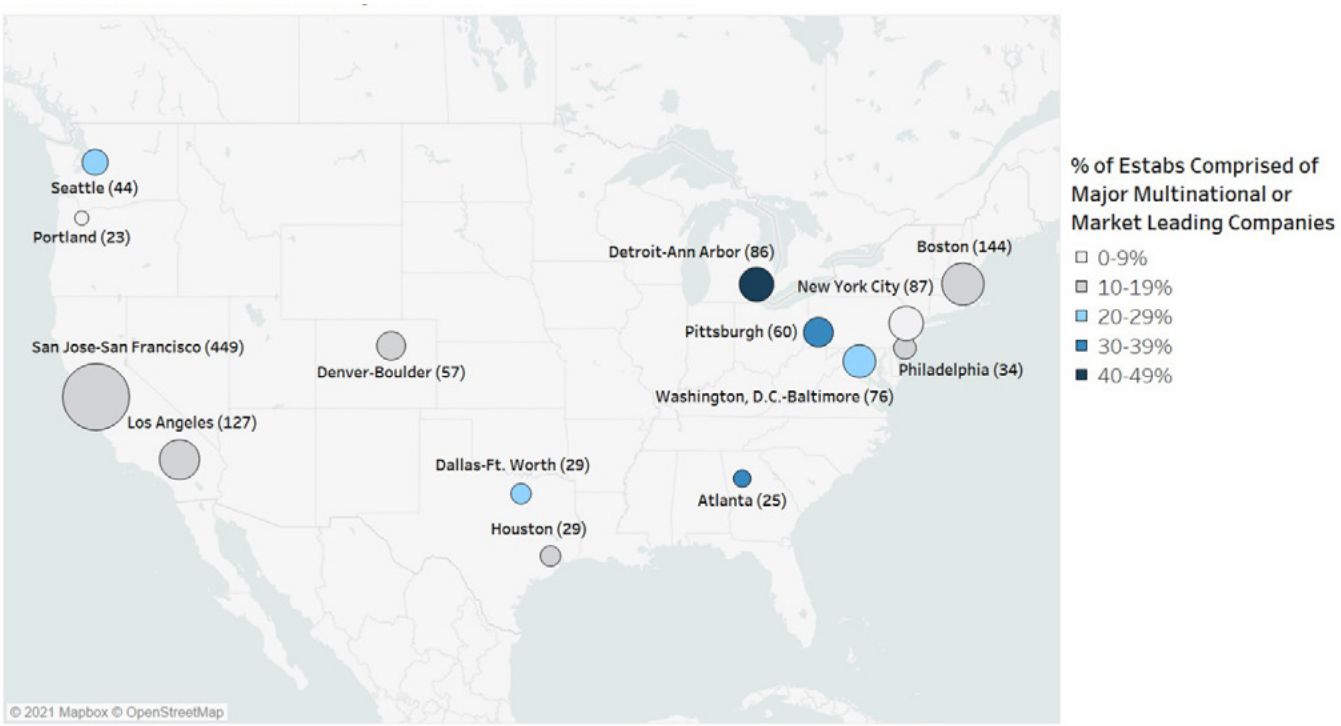
## FIGURE G1.
## U.S. Autonomous Mobile Systems Establishments Distribution by CSA




***Source:*** *TEConomy analysis of custom database of U.S. autonomous mobile systems companies*

Analysis of this database suggests that Pittsburgh maintains several key advantages in its level of industry activity. First is the concentration of leading companies or branches of major multinationals as described in the previous section. Pittsburgh has strong representation in both areas with the presence of key companies such as Aurora, Argo AI, Caterpillar, and Denso. Aside from the Detroit-Ann Arbor region, no other city has such a high proportion of major multinationals or other significant players in the autonomous mobility space (Table G1 and Figure G2).

**FIGURE G2.**
U.S. Autonomous Mobile Systems Establishments by CSA and Concentration of Leading Companies

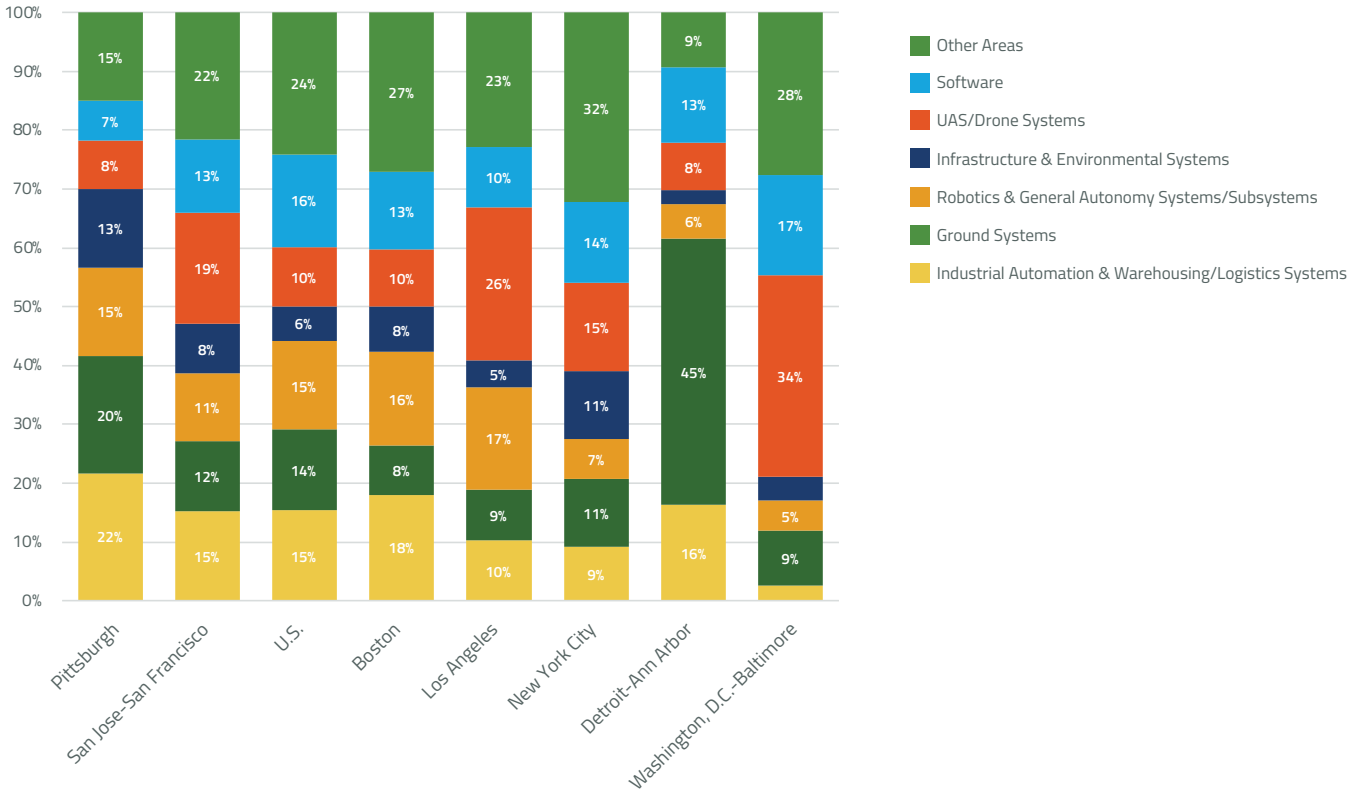



***Source:*** *TEConomy analysis of custom database of U.S. autonomous mobile systems companies*

Pittsburgh's other major advantage evident in this dataset is its composition of different industry areas. Autonomous mobility-related companies in Pittsburgh are relatively evenly distributed along key industry areas, with particularly strong concentration in Industrial Automation & Warehousing/Logistics Systems, Ground Systems, Robotics & General Autonomy Systems/Subsystems, and Infrastructure & Environmental Systems. Neither the U.S. nor any other sizable region in the database hold a relative advantage across those four key areas which represent Pittsburgh's strengths, as shown in Figure G3.

**FIGURE G3.**

## Percentage of U.S. Autonomous Mobile Systems Establishments by Region and Industry Area




***Source:*** *TEConomy analysis of custom database of U.S. autonomous mobile systems companies*

# Appendix H:
## Profile of Pittsburgh's Current Autonomous Systems Industry and its Economic Impact

In order to profile the current footprint of Pittsburgh's autonomous systems industry, TEConomy identified 71 local firms (or in cases of major multinational corporations, divisions, or operating units of those firms) that had core business operations that primarily served the autonomous systems industry. These firms, comprising various elements of the autonomous systems technology stack, were initially identified from various innovation and workforce activity indicators, including:

- Regional patent award assignees (see Appendix D)
- Venture capital investment in regional companies in autonomy-related technology verticals (see Appendix D)
- SBIR awards for autonomy-related research (see Appendix D)
- Regional companies receiving contract dollars for autonomous systems-related products or services in the Federal Procurement Data System (FPDS)
- Regional companies with autonomy-related job postings activity (identified using Emsi JPA, see Appendix F)
- Autonomy-related companies involved in Innovation Works or other regional program activities serving emerging businesses
- Presence in market research reports or press releases relevant to national and regional autonomy markets

Initial listings of regional companies were reviewed by regional stakeholders and the project steering committee to determine their status as well as their alignment to the context of the study. This analysis does not include companies whose alignment to this space could not be determined or who did not have at least one discrete business unit whose core products or services were directly involved in autonomous mobile systems. As a result, this accounting of the regional autonomous systems industry is conservative since it does not include additional firms not focused primarily on autonomy whose products and services still provide key enabling capacities.

Using a combination of the data sources described above and supplemented both by company LinkedIn profiles and direct interviews with industry stakeholders, TEConomy identified best available estimates of employment levels associated with each of the companies. Additionally, TEConomy researched company activity in key technology areas as well as end market applications to determine the primary areas of business activity associated with each company (note that a company is almost always active in multiple technology areas and potentially in multiple end market applications as well). Where possible, TEConomy verified these areas of activity in direct interviews with industry stakeholders. Figure H1 below shows the perspective of employment concentration in combinations of technology areas and end markets for the set of Pittsburgh companies active in the autonomous systems industry.

**FIGURE H1.**

## Estimated Current Employment at Autonomous Systems Companies in Pittsburgh, by Technologies Deployed and Markets Served*


***Note:** companies may deploy multiple technologies and serve multiple end markets as a part of their business activity*

***Source:** TEConomy analysis of Pitchbook VC, SBIR, USPTO, company LinkedIn profile, and other data*

The firms identified above represent an estimated total of 6,319 regional jobs. To illustrate the value the industry provides to the Pittsburgh region today, TEConomy analyzed the impact of this group of firms in terms of the economic benefit they provide to the regional economy. Quantifying the economic footprint of an industry relies on tying employment in industry sectors to the economic output they produce. Output is defined as the dollar value of goods and services produced by a company and summing output across all companies in an industry yields total industry output. The footprint of an entire industry in terms of its output is commonly known as the industry's economic impact and can be categorized within the context of the region's larger economic output to determine the importance in driving overall economic activity.

The economic impact analysis of Pittsburgh's autonomous systems industry makes use of a custom economic Input/Output (I/O) model that quantifies the interrelationships between economic sectors in the regional economy, allowing for estimation of the impacts of one sector on all other sectors with which it interacts. The measured economic impacts of an autonomous systems technology company within this model consist of three types:

- **Direct effect:** The dollar valuation of all goods and services provided as output by a company
- **Indirect effect:** The valuation of all of the inter-industry transactions between a company and other companies that supply the materials or services required to produce output
- **Induced effect:** The valuation of household income supported by the company through expenditures its employees make at other local industries.

Together, these three impacts comprise total economic impact. I/O analysis thus models the flow of funds that originate from direct autonomous systems industry expenditures in the economy and the ongoing ripple (multiplier) effect of these expenditures. In other words, economic impact models are based on the concept of the "multiplier"—that every dollar spent in the economy is re-spent one or more times, thereby generating additional economic activity and impact.

The current estimated impacts of the Pittsburgh region's autonomous systems industry were calculated using 2019 region-specific I/O models generated by the IMPLAN Group (one of two major developers of nationally and regionally-specific I/O tables and analytical systems). These models are built primarily from the U.S. Bureau of Labor Statistics' Quarterly Census of Employment and Wages (QCEW, tied to unemployment insurance reporting). These data provide detailed intelligence on the number of establishments, monthly employment, and quarterly wages, by North American Industry Classification System (NAICS) industry, by county geography, by ownership sector, and for the entire U.S. The IMPLAN model employment data is further enhanced by U.S. Bureau of Economic Analysis data to account for sole proprietorships and other very small firms that fall outside of the QCEW data collection protocols.

For this analysis, a customized model was developed to quantify the direct, indirect and induced impacts of the autonomous systems industry. Given the nascent and emerging nature of the autonomous systems industry no single NAICS code reflects the industry. Additionally, the role any specific firm plays within the industry can vary widely. To best reflect the industry within the IMPLAN model three autonomous systems industry subsectors were defined as groups of IMPLAN sectors or aggregations. These subsectors include:

- **Robotics and automation component manufacturing,** consisting of component and equipment manufacturers whose NAICS codes reflect miscellaneous industrial machinery, industrial material handling equipment, semiconductor components, and various instruments and controls.
- **Software, programming, and integration,** consisting of software design and publishing firms, data processing and analytics firms, and custom computer programming and computer system design services.
- **R&D and engineering services,** consisting of engineering and related technical service firms, firms focused specifically on R&D efforts, and management consulting/analysis service firms.

The following data are output from each model: employment (combined number of full and part-time workers), personal income (measures cash, benefits and non-cash payments received by individuals in the economy), value added (the difference between an industry's or an establishment's total output and the cost of its intermediate inputs), economic output (the dollar value of sales, goods, and services produced in an economy, is sometimes referred to as business volume, and represents the typical measure expressed as "economic impact" in a standard economic impact study), state and local tax revenue (including sales, income, and property taxes), and federal tax revenue (including sales and income taxes, and both corporate and employee contributions to Social Security).

The estimated direct employment footprint of Pittsburgh's autonomous systems firms totals 6,319 jobs which provide an estimated $651 million in labor income, $34.7 million in state and local tax revenues, and $126.7 million in federal tax revenues. These companies generated a further 8,604 full or part time jobs through indirect and induced effects to support a total of 14,923 jobs in the region. Estimated business revenues from the autonomous systems industry added approximately $1.5 billion in business volume to the regional economy and contributed an additional $1.5 billion in business volume through indirect and induced business spending to support a total economic output footprint of nearly $3 billion dollars (see Table H1) .

**TABLE H1.**
## Economic Impact Results for Current Pittsburgh Autonomous Systems Industry Employment

| Impact Type | Employment | Labor Income ($M) | Value Added ($M) | Output ($M) | State/Local Tax Revenues ($M) | Federal Tax Revenues ($M) |
|---|---|---|---|---|---|---|
| Direct Effect | 6,319 | $650.9 | $835.0 | $1,514.1 | $34.7 | $126.7 |
| Indirect Effect | 3,227 | $248.5 | $357.8 | $621.5 | $24.0 | $50.4 |
| Induced Effect | 5,377 | $297.1 | $505.7 | $859.4 | $46.5 | $64.9 |
| **Total Effect** | **14,923** | **$1,196.5** | **$1,698.6** | **$2,995.0** | **$105.2** | **$242.0** |
| *Multiplier* | *2.36* | *1.84* | *2.03* | *1.98* | | |

The effect that direct industry spending and employment has on economic activity across all other industries in the state is known as the industry's multiplier. One employee in the autonomous systems industry today supports approximately 2.36 additional employees in other industry sectors, and every $1 in spending from the autonomous systems industry generates an additional $1.98 in economic output from other industry sectors.

As noted above, this analysis represents a conversative estimate of the total economic and functional impact provided by the industry to the region as there are additional firms not focused primarily on autonomy whose products and services still provide key enabling capacities for the autonomous systems technology stack. The analysis also does not include the potential economic impact on the wide base of existing companies located in the Pittsburgh region who could reap the benefits of autonomous solutions as they are commercialized and deployed, in turn making local manufacturing, production, business services, and other industries more innovative and competitive and driving their employment growth.

# Appendix I:
# Listing of Stakeholder Interviews Conducted by TEConomy

## Academic Institutions

- CMU School of Computer Science
- CMU Metro21 Institute
- University of Pittsburgh Swanson School of Engineering

## Autonomous Systems Industry Companies

- Aurora
- Argo AI
- Advanced Construction Robotics
- Aethon
- Carnegie Robotics
- Caterpillar
- Edge Case Research
- Locomation
- Neya Systems
- Motional
- Robert Bosch
- Seegrid
- Titan Robotics
- IAM Robotics
- Kaarta
- Near Earth Autonomy

## Regional Innovation and Economic Development Ecosystem Organizations

- Pittsburgh Tech Council
- Pittsburgh Regional Alliance
- Greater Pittsburgh Chamber of Commerce
- Innovation Works
- Pittsburgh Robotics Network
- Coal Hill Ventures Robotics Hub
- ARM Institute

# Appendix J:
# Benchmarking Other Major Autonomy Initiatives in the U.S.

## California – Silicon Valley Robotics

### What it Is

Silicon Valley Robotics (SVR) is a coalition of robotics-interested companies clustered in northern California. Its members include established companies, startups, and professional-service providers with an interest in the cluster.

### Mission and Goals

SVR's stated mission is "to support the innovation and commercialization of robotics technologies."

### Funding

Launched in 2010, SVR is organized as a not-for-profit corporation recognized as exempt from federal taxation under IRC §501(c)(6) – the exemption applicable to membership-based trade associations. Membership dues or sponsorships are therefore not deductible from taxable income as charitable contributions, but only if necessary business expenses.

According to the latest available IRS Schedule 990EZ filed by SVR, the organization should be considered a grass-roots effort. Its revenues in 2018 were $160,400, the majority of which came from program service revenue and the balance from membership dues. Year-end net assets were $11,900. The managing director was paid $60,000. It is, however, possible that SVR has grown since 2018.

Dues begin at $99 for an introductory membership and rise to $300 for startups (including eligibility for demo days) and $600-$5,000 depending on size for established companies. The main benefits for larger members are invitations to speaker salons, opportunity to be featured in SVR reports and expos, and access to a résumé database and job fairs.

There is no obvious support from any government unit.

### Main Programs

- Silicon Valley Robot Block Party
- Networking events and investor forums
- Roboticist in residence
- Directory, learning database, and jobs board
- Annual accelerator and startup competition with demo day
- Research reports on the industry
- Robotics Industry Awards

SVR operates from SVR CoLab, its coworking space in Oakland.

### Key Members

The following companies are identified as SVR founders:

- Fetch Robotics
- Festo
- EandM Engineering
- SICK Sensor Intelligence
- SRI International

- Cruise Automation
- Harmonic Drive

Several of these founders are additionally listed as sponsors, along with ARM, Panasonic, Toyota Research Institute, and Bossa Nova (a startup).

SVR does not emphasize membership by universities, but the Stanford University School of Engineering is represented in the membership by an individual.

## Innovation Environment

SVR has counted 50 national and university robotics labs in its service area and has mapped them. SVR makes no attempt to categorize these labs by size, reputation, or importance or involvement in SVR.

Leaving aside NASA Ames and other federal labs, to the extent that there is a dominant multi-investigator, university-based center of R&D on autonomy, it is the "People and Robots" research area within CITRIS and the Banatao Institute. This latter entity is a multicampus research unit of the University of California, which grew from the state's investment in "Cal Institutes" for academic/industrial collaboration and from a privately endowed institute. CITRIS/Banatao does not appear to be a member of SVR.

## Policy Environment

California has no well organized state-level agency for innovation policy. To the extent autonomy is a concern of state government, it is focused strictly on autonomous vehicles, and responsibility for testing permits is assigned to the Department of Motor Vehicles.

However, for many years the State of California has supported an Institute for Transportation Studies (ITS) that is distributed across multiple campuses of the University of California. In 2020 the ITS published on behalf of its state-government stakeholders an excellent review of the policy environment for autonomous vehicles (the only aspect of autonomy considered) across the United States.

ITS has further proposed that it house a "California Innovative Mobility Initiative (CA IMI)" also known as the "California Resilient and Innovative Mobility Initiative (CA RIMI)." Under either name, this is more a systems-level effort than an exercise in the development of technology for autonomy, and it is strictly focused on vehicles. ITS positions CA IMI/CA RIMI as a next-generation successor to the wave of state-level policy initiatives it surveyed in its policy review.

# Massachusetts – Mass Robotics

## What it Is

MassRobotics could be classified as a cluster-development organization organized around a special-purpose business incubator featuring a collection of specialized prototyping and testing facilities aimed at startups in robotics and connected devices. Startup residency and programming is supported/cross-subsidized by contributions from larger companies, government agencies, and service providers.

## Mission and Goals

The mission is "to help create and scale the next generation of successful robotics and connected device companies by providing entrepreneurs and innovative robotics/automation startups with the workspace and resources they need to develop, prototype, test and commercialize their products and solutions" (from IRS Schedule 990).

Further, "Through our programming and events, we help bring together innovative startups and existing technology organizations to nurture the next generation of talent, and promote economic growth and innovation. By working with diverse local talent, we are helping to bring about the next global evolution of robotics. The organization promotes the development of common-need technology services, such as software and standards support for the robotics community, foster a collaborative ecosystem for academic, private, and public key stakeholders that allows thought-sharing and creative exchange, and inspire the next generation of innovators and builders through in-house hands on STEM collaboration and initiatives."

## Funding

MassRobotics is a not-for-profit corporation founded in 2015 as an outgrowth of the Mass Robotics Cluster, an unincorporated program of the Massachusetts Technology Leadership Council. MassRobotics is recognized as exempt from federal taxation under IRS §501(c)(3), the classification for publicly supported charitable efforts.

According to the latest IRS Schedule 990 filed by MassRobotics, revenues in 2019 were $4.2 million, up very substantially from prior years. Year-end net assets were $3.6 million, also up. Of total revenue in 2019, $2.5 million was reported as "government grants," though without access to full financial statements it is not possible to say from which level of government or whether unrestricted or categorical.

The top two executives – the director of robotics and the executive director – were paid $174,000 and $125,000 respectively in 2019.

Membership dues are not disclosed, but tiers run: $1 million - $5 million in revenue; $6 million - $10 million; $11 million - $25 million; $26 million to $50 million; $50 million - $100 million; $100 million - $500 million; and $1 billion and up.

## Main Programs

Opened in 2017, the now-40,000 square-foot MassRobotics Hub at the Boston Seaport Innovation District is a type of incubator offering private offices, coworking space, a machine shop, private lab benches, access to software and CAD tools; electronics and prototyping facilities, discounted hardware and component purchases from partners; marketing and promotion; mentor support; and event space. In addition, MassRobotics supports activities such as:

- Opportunities for larger companies and service providers to engage with residents of the hub incubator
- Market research and industry reports
- Targeted executive briefings
- Pitch sessions for startups
- Technology meetups and workshops
- Community outreach and STEM programming

- MassRobotics Ecosystem database and map
- Collaborations with the Innovation Institute at the Massachusetts Technology Collaborative, such as a recent event on the future of robotics.
- Development and publication of standards by an Autonomous Mobile Robots Interoperability Working Group, formed in 2020.

## Key Members

The following companies are listed as MassRobotics founders:

- Vecna Robotics
- CIC
- Amazon Robotics
- Harmonic Drive
- Autodesk
- Arrow
- IDA Ireland
- iRobot
- Deshpande Foundation
- DS Solidworks
- BRC

Several of these founders are additionally listed as annual partners:

- Analog Devices
- MITRE
- Mitsubishi Electric
- GM
- Festo
- Cowen
- Panasonic
- The Robot Report
- SMC
- AeroVironment
- FedEx
- MassDevelopment
- FoleyHoag LLP
- Massachusetts Clean Energy Center
- Thomas H. Lee Partners
- Newmark Grubb Knight Frank
- Massachusetts Tech Collaborative
- Massachusetts Technology Leadership Council
- Robotic Industries Association
- Altium
- Masschallenge
- MathWorks
- Mower

Current resident startups and anchor tenants include (not all of these yet have active websites) a range of companies spanning multiple underlying technologies and targeted markets:

- 4d Space Genius Inc.
- Activ Surgical
- AirShare
- AIT (Australian Institute of Technology)
- Ascend Robotics
- Autonodyne
- Ava Robotics
- Avendly
- Black-i Environmental
- Black-i Robotics
- Bobbin Embedded
- Cleo Robotics
- Collabots
- ConfiTemp
- Deep-AI Technologies
- Dive Technologies
- Elistair
- Evergreens
- Flora.Bot
- FringeAI
- Greensight
- Hathaway Robotics
- Haystack Ag
- InnovaSea Systems
- Institute for Experiential Robotics of Northeastern University
- Kraken Robotics
- Maglev Aero
- Mapless AI
- Mente
- Minigrid
- MVP Robotics
- Neurala
- NeXtera
- Open Source Robotics Foundation
- Ori
- Pison Technology
- Ras Labs
- RealBotics
- Realtime Robotics
- RGS Automation
- Scalable Robotics
- Southie Autonomy
- Spiral Solutions
- TargetArm
- Tennibot
- ThayerMahan

- TruPhysics
- Thinking Robots
- Tutor
- Ubiros
- URBX
- Watertower Robotics
- Waypoint Robotics
- The Ventilator Project
- Xnergy

## Innovation Environment

In 2014, the state-funded "Collaborative Research Matching Grant Program" operated by the Innovation Institute at the Mass Tech Collaborative awarded $5 million to the Woods Hole Oceanographic Institute on Cape Cod for a new/renewed facility for WHOI's Consortium for Marine Robotics.

In 2016, the state-supported quasipublic Massachusetts Technology Collaborative (MTC) published a study it had commissioned from a consulting firm on "The Massachusetts Robotics Cluster." This report considered autonomy and intelligent systems broadly across a full taxonomy embracing robots in industry; logistics; the consumer sector; the educational/research sector; and (then)-emerging markets such as unmanned underwater vehicles and automated and autonomous vehicles. The report also assessed the state of enabling technologies (IoT, cloud/distributed robotics, AI/ML/DL, and robot operating systems). It also included comprehensive inventory of relevant in-state educational and research assets; incubators, accelerators and workspaces; national laboratories and military installations.

In a report dated February 2019, the AV Working Group (see below) included a survey of the industry in Massachusetts, identifying important in-state developers of automated driving systems and of underlying hardware and software, including a range of private-sector companies and also MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) and other university-based initiatives statewide. The report highlights the $25 million investment in automated driving systems made in CSAIL by Toyota in 2015, and identifies MassRobotics as an industry-driven developer of shared technology services such as prototyping and testing space. "While Massachusetts may no longer be a location for the manufacturing and assembly of vehicles," this section concluded, "a range of companies and institutions within the State continue to play an essential role within the industry." At the time of the AV Working Group report, the Massachusetts legislature had already passed Acts of 2018 Chapter 228, which required MTC to conduct and publish by the end of 2019 a more holistic study of the autonomous vehicle industry. However, TEConomy Partners was unable to locate a publicly available copy of this report.

Currently the MassRobotics ecosystem database tracks 350 innovative companies serving 11 markets; 35 university-based robotics R&D programs across 18 institutions; the NIST test facility at UMass Lowell known as the New England Robotics and Experimentation (NERVE) Center; Joint Base Cape Code, an FAA test site for unmanned air systems; and the Center for Marine Robotics at Woods Hole Oceanographic Institute.

## Policy Environment

As long ago as 2016, possibly in alignment with release of the report on the robotics cluster, the chief executives of both the state and city government had signed executive orders designed to position the region as a center of autonomous vehicle development.

- Governor Charlie Baker's Executive Order 572 created a cross-government AV Working Group chaired by the Secretary of Transportation but also involving four other agency heads and bipartisan representation from the state Legislative leadership. The AV Working Group was given the specific charge to "encourage the development of autonomous vehicles and their component parts in Massachusetts and to that end shall work with companies in the sector to support

innovation and development and consider proposing changes to statutes or regulations that would facilitate the widespread deployment of highly autonomous vehicles in Massachusetts while ensuring the safety of the public."

- At about the same time, then-Mayor Martin Walsh of Boston signed an unnumbered executive order directing the city Transportation Department to lead oversight of testing and policy development, emphasizing regulatory permissions that liberalize in line with actual accomplishments, reliance on open data standards, affirmative efforts to achieve equitable access, and coordination with other modes of mobility.

In 2018, the state Department of Transportation entered into a Memorandum of Understanding with several cities and towns that streamlines the process for companies seeking to test AVs on Massachusetts roads. This arrangement appears to have replaced an earlier reliance on testing at the former Fort Devens site being redeveloped for mixed use by the quasipublic MassDevelopment financing agency.

## Ohio – DriveOhio

### What it Is

DriveOhio is a formalized consortium of state agencies involved in "smart mobility," managed through an office of the Ohio Department of Transportation (ODOT) and able to contract under the latter's authority.

(The robustness of this organizational affiliation has allowed DriveOhio through ODOT to issue a single, unified RFI on behalf of the multistate Smart Belt Coalition, whose members also include PennDOT, the Pennsylvania Turnpike Commission and CMU, along with opposite numbers in Michigan.)

Drive Ohio has partners across more than a dozen Ohio state agencies spanning multiple functions. DriveOhio and its partner agencies seed projects that attract federal grant funding knitting together diverse state and federal assets in the interest of smart mobility advances.

The executive director of DriveOhio reports to the Director of ODOT, under the guidance of both government and industry advisory boards. Each of the other Ohio state-agency partners must designate a dedicated liaison to DriveOhio.

Interagency workgroups managed by DriveOhio those dedicated to:

- Data, analytics, and security
- Infrastructure
- Education and workforce development
- Unmanned aerial systems
- Telecommunications and right of way
- First mile/last mile
- Vehicle deployment
- Budget and partnerships
- Communications and public education
- Policy and regulations
- Economic development

### Policy Environment

DriveOhio was initially created by Executive Order 2018-01K signed by then-Governor John Kasich; designated as the point of registration for companies wishing to test autonomous vehicles on Ohio roadways by Kasich's EO 2018-04K; and renewed by

current Governor Mike DeWine under EO 2019-26D with a far-more explicit focus on standards development and deployment, technological innovation, and economic and workforce development.

## Mission and Goals

DriveOhio's stated mission is "advancing smart mobility in Ohio and being a one-stop shop for those looking to develop, test and deploy advanced mobility solutions in Ohio."

DriveOhio brings together all public and private entities "involved in the design, development, testing, use and regulation of autonomous and connected technologies . . . [and] . . . works to ensure Ohio's regulatory environment and public policies are conducive to the development of the infrastructure and technologies needed for smart mobility . . . [and] . . . fosters cooperation and collaboration, offers faster access to resources by breaking down government barriers, and improves efficiencies for people and organizations that want to be part of this industry."

The currently applicable executive order specifies five core values of the program: safety; mobility; access; reliability; and talent (SMART).

## Funding

DriveOhio does not appear as a separate line item in the budget of the state Department of Transportation or any of the partnering state agencies. However, it both influences allocation of appropriations to DOT and all its partners, and influences receipt of federal grant funding by ODOT and partners.

## Main Programs

DriveOhio identifies five programmatic groupings, not all of which are strictly related to vehicular autonomy:

- Smart logistics – under DriveOhio's nomenclature, this area refers to trucking logistics, not warehousing automation. Key projects include corridors instrumented for maximum automation along State Route 33 northwest of Columbus and along I-70 in collaboration with Indiana, both of which projects were seeded with state support from DriveOhio and then subsequently received federal grant support.
- Unmanned aerial systems – the ODOT-funded and managed Unmanned Aircraft Systems (UAS) Center now reports directly to the DriveOhio executive director. Key projects of the UAS involve using Unmanned Aerial Vehicles to help ODOT district offices monitor ground traffic and infrastructure conditions while also ensuring flight operations are safely compatible with Ohio's airports. The UAS Center is also DriveOhio's primary interface with autonomy programs at the Air Force Research Laboratory in Dayton.
- Electrification – not directly an autonomy topic
- City solutions – DriveOhio is supporting development of intermodal "mobility hubs" including first/last mile autonomous shuttles in Columbus under a major federal Smart City award and at smaller scale in several other Ohio cities.
- Rural mobility – this appears to be mainly a catch-all category for corridor projects that pass through rural areas.

## Key Members

DriveOhio is not a membership organization, but as of 2019 its industry (expert) advisory board includes representatives from:

- The Transportation Research Center, Inc. (see below under Innovation Environment)
- DENSO
- Greater Dayton Regional Transit Authority
- Ford
- General Motors
- Honda R&D Americas

- Marathon Petroleum
- Ohio Telecom Association
- American Automobile Association
- Lyft
- Bosch
- Kroger

The Government Advisory Board includes representatives from city governments, universities, and regional councils of governments or regional planning commissions (which often serve also as USDOT/FHWA-recognized metropolitan transportation organizations):

- Smart Columbus (see below under Innovation Environment)
- Northwest 33 Innovation Corridor Council of Governments (see below)
- Eastgate Regional Council of Governments
- Mid-Ohio Regional Planning Commissions
- Central Ohio Transportation Authority
- City of Athens
- University of Toledo

### Innovation Environment

Through DriveOhio, the ODOT and JobsOhio committed $45 million to a new Smart Mobility Advanced Research Center (SMART Center), an automated and connected vehicle-testing facility to be built on 540 acres of the current grounds of the long-standing Transportation Research Center (TRC). The TRC is a state-chartered not-for-profit that bills itself as the largest independent vehicle test facility and proving grounds in the nation. It contracts for management and research services with OSU. This partnership is continuing to leverage state investments with new federal grants, such as a recent award of $7.5 million toward a $17.8 million state DOT project to bring advanced technologies to Ohio's rural highways. Ultimately these state and federal awards flow to OSU.

## Michigan – Mcity

### What it Is

Created in 2014, Mcity is a test facility combined with an industry-sponsored research program, all housed at the University of Michigan. The facility is a 32-acre artificial urban/suburban setting equipped with 5G vehicle-to-everything service, supplemented by an augmented reality lab that simulates traffic, "digital twins" of the physical setup, and a common API for control.

### Mission and Goals

Mcity's tag line is "Leading the transformation to connected and automated vehicles." In more detail: "Here, we bring together industry, government, and academia to advance transportation safety, sustainability and accessibility for the benefit of society."

### Funding

Mcity claims a cumulative total of $26.5 million invested since 2015 in research, development and deployment projects, but no detailed budget or breakdown by year or source is published.

The center also recognizes in-kind support from the City of Ann Arbor, which operates its own federally supported Ann Arbor Connected Environment (AACE). To date Mcity has extracted 50 million miles of data from the AACE and in collaboration with

the University of Michigan Transportation Research Institute (leveraging additional federal grants) has instrumented the AACE for near-real-time data collection from 2,500 connected vehicles and 70 connected intersections across Ann Arbor.

## Main Programs

The program encompasses currently about 20 active research projects for which funds from industry sponsors are pooled. These projects are categorized as pertaining to either safety, accessibility, efficiency, or commercial/economic viability.

The program involves some 50 faculty members across campus, who produce both academic publications and white papers aimed at general and industrial audiences. A collaboration with the UM College of Engineering Center for Entrepreneurship also supports student participation in mobility startups through the "TechLab at Mcity." Finally, Mcity conducts general public outreach.

One important but now-closed project was an autonomous shuttle that ran at the test site through December 2019, completing 16,000 trips.

## Key Members

Mcity claims 59 industry partners. The following are highlighted as members of the Leadership Circle, each having committed $1 million over three years, as defined in a formal membership agreement with milestones:

- Aptiv
- Denso
- Econolite
- Ford
- GM
- Honda
- StateFarm
- Toyota
- Verizon

Additional "affiliates" that have committed at least $150,000 over three years include a mix of manufacturers and technology and service providers:

- 3D Mapping Solutions
- 3M
- AARP
- Aioi Insurance Services
- Analog Devices Inc.
- Bitsensing
- Bowman and Brooke LLP
- CARMERA
- Covington & Burling LLP
- Daikin America Inc.
- Danlaw Inc.
- Deloitte Consulting LLP
- Desjardins General Insurance Group Inc.
- Dow Coating Materials
- Dykema
- EdgeConneX

- Foretellix
- Fortive
- Goodyear Tire and Rubber Company
- Harada Industry of America Inc.
- HERE
- Hitachi Ltd.
- Incorta
- Intel
- Isuzu Technical Center of America Inc.
- JD Power
- Latham & Watkins LLP
- Lear Corporation
- Marathon Petroleum Corporation
- Mechanical Simulation Corporation
- Metamoto
- Miller, Canfield, Paddock and Stone PLC
- NAVYA
- Nexteer Automotive
- NovAtel
- OnBoard Security
- Progressive Casualty Insurance Company
- RAB Lighting Inc.
- SAIC Motor Corporation Limited
- Seoul Robotics Ltd.
- SF Motors Inc.,
- Siemens Digital Industry Software
- Subaru
- Swift Navigation
- Voxel51
- Warner, Norcross & Judd LLP
- ZF

## Innovation Environment

The state Council on Future Mobility and Electrification (see below) considers M-City one of five key proving grounds and testing sites for advanced mobility, along with

- the Michigan Unmanned Aerial Systems Consortium in Alpena;
- the American Center for Mobility in Ypsilanti;
- the Michigan Technical University in Houghton; and
- the Kettering University/GM Mobility Research Center in Flint.

These latter entities are not profiled here.

## Policy Environment

In 2020, Governor Gretchen Whitmer signed Executive Order 2020-2 creating the Michigan Council on Future Mobility and Electrification (CFME), housed within the Department of Labor and Economic Opportunity (LEO). This advisory and coordinating

board addressing government issues posed by autonomous vehicles replaces the Council on Future Mobility created by former Governor Rick Snyder. The council comprises the following members:

- The director of the LEO department
- The director of the Department of Environment, Great Lakes, and Energy
- The director of the Department of Insurance and Financial Services
- The director of the Department of State Police
- The director of the Department of Transportation
- The director of the Department of Treasury
- The chair of the Michigan Public Service Commission
- Nine individuals appointed by the Governor representing the local government, business, policy, research, or technological leaders and one representing insurance
- Non-voting members representing both parties, both houses, in the Legislature

The individuals currently representing private interests are affiliated with:

- GM
- Ford
- Stellantis
- Waymo
- Toyota
- Rivian
- Michigan Energy Innovation Business Council
- United Autoworkers union
- University of Michigan
- Michigan State University

In 2020 the Council produced a substantive report of its activities assessing the state's ability to navigate coming technological changes in mobility such as autonomous driving, vehicle connectivity, powertrain electrification, shared mobility, intelligent automation, and globalized supply chains. The primary conclusions include:

- "There is a global competition to determine where advanced vehicle technologies will be built."
- "Michigan's mobility assets include the nation's largest concentration of private-sector facilities; a robust network of universities, state and federal offices; collaborative efforts between the private sector, academia and state agencies. . . ."
- ". . . more skilled workers will be needed to help the industry continue to grow."
- "Large investments in electrification and automation give Michigan an edge in these critical technologies, but there is room to grow when it comes to private sector investment and mobility startups in the state."

At the same time an Office of Future Mobility and Electrification (OFME) was created within LEO, with staffing and support provided by the Michigan Economic Development Corporation (MEDC) the state's business-attraction and economic-development financing agency. MEDC had previously branded its mobility initiatives under "PlanetM" but as of 2021 the brand was sunset and the MEDC team now supports OFME, according to the CFME report.

Governor Gretchen Whitmer's FY22 budget proposal calls for a total of $25 million to be spent on a Mobility Futures Initiative coordinated by the OFME in LEO. Of this amount, an undetermined share will be allocated to programs that seem likely to have high relevance to deployment of connected and autonomous vehicles. Among the highlighted programs with high relevance to autonomy as opposed to electrification are "Future Proof Logistics Corridors" and "Toolkit to Attract Top Autonomous Vehicle and Electric Vehicle Companies."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