Capturing the next economy: Pittsburgh's rise as a global innovation city

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The Anne T. and Robert M. Bass Initiative on Innovation and Placemaking

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Cover Image: Aerial view of downtown Pittsburgh.
Photo credit: Urban Redevelopment Authority of Pittsburgh.

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Executive Summary

Few cities have experienced the economic upheaval that Pittsburgh did in the 1970s and 1980s—and come back. During the country's industrial heyday, the city swelled in population and income. Yet by 1980, global economic forces had shuttered much of the U.S. steel industry, and Pittsburgh's unemployment rate reached 18 percent as Western Pennsylvania effectively experienced a second Great Depression.

Today, the competitive advantage of the region is no longer its rivers and raw materials but its high-skilled workers, world-class research institutions, and technology-intense advanced manufacturing. In 2016, for example, the region's per capita university research and development (R&D) spending was nearly two and a half times the national average. While these assets are considerable, they also place Pittsburgh in competition with a number of other innovation cities that are rapidly investing billions in a suite of new technologies and industries poised to reshape the global economy.

As in the past, the cities at the forefront of these economy-shaping technologies will be the focal points of global capital, talent attraction, and firm growth. If approached correctly, follow-along economic activity and investment will in turn lead to more and better-paying jobs—with varying skill-level needs and across multiple sectors of the economy—and higher revenues that can be reinvested in education, workforce development, infrastructure, and neighborhood revitalization.

However, Pittsburgh's scientific and technical strengths have not fully translated into broad-based economic activity. In fact, if the region had the same share of high-tech employment as university research, it would employ 9,000 more in the software industry and 5,500 more workers in drug development, not to mention tens of thousands of workers in related jobs. Instead, the city currently has seven percent fewer jobs in high-wage, high-tech advanced industries than it did in 2000.

Without a robust platform of jobs at all skill levels, the city's significant research and technical strengths will fuel only a small portion of the region's economy and leave many workers and families behind.

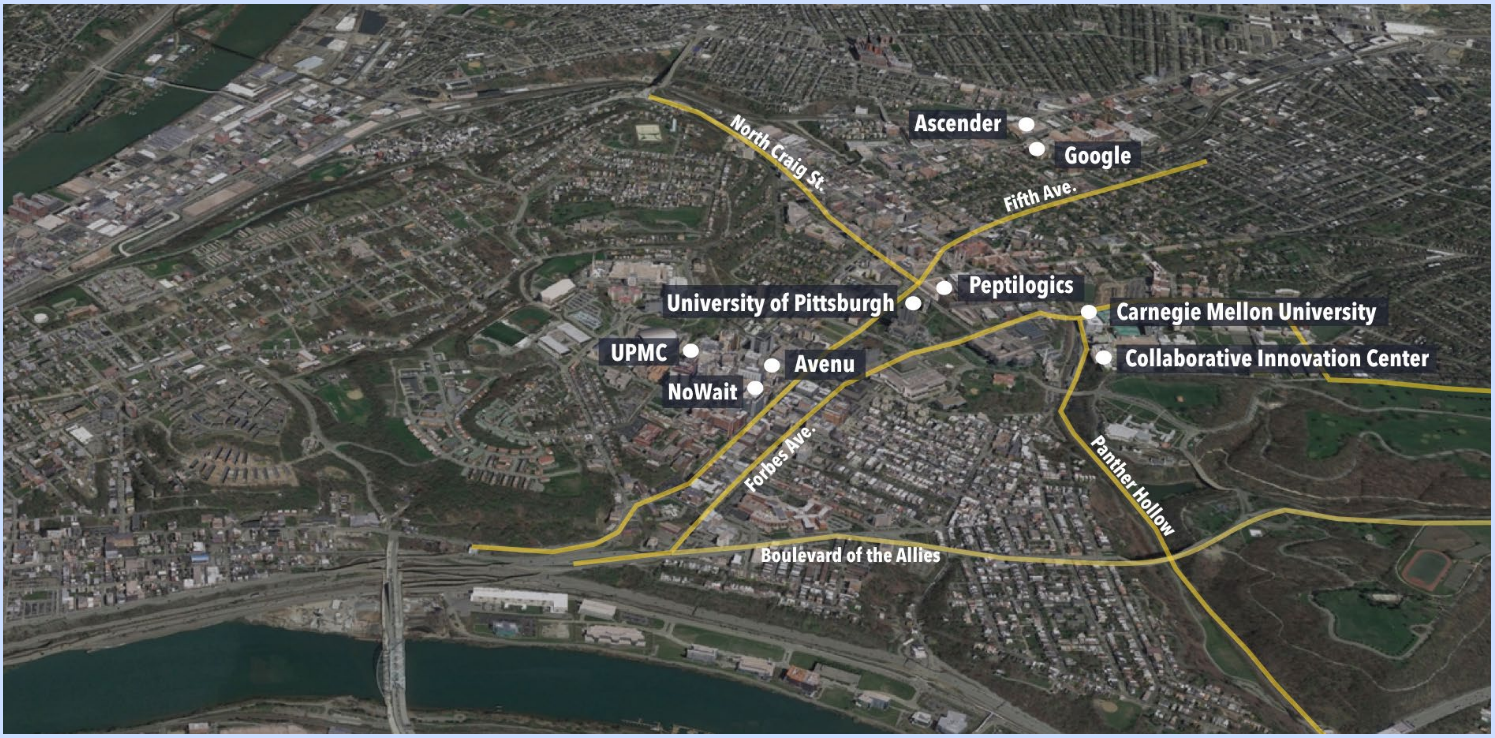
Today, Pittsburgh is once again at the precipice of a new competitive reality. In the 1980s, the city was on the losing end of shifts in the global economy. Now, in the modern, innovation economy, the city can choose its own fate. Success or failure will be determined by the speed and scale of actions taken by public, private, and civic leaders.

The Oakland Innovation District

Just as Pittsburgh's opportunity is contextualized by a changing global economy, the spatial geography of innovation is changing as well. Cities in both the United States and abroad are witnessing the emergence of dense hubs of economic activity where innovation, entrepreneurship, creativity, and placemaking intersect. At the advanced, research-led end of the economy, innovation districts are developing around anchor institutions (such as universities, medical centers, and large firms) that are in close proximity to talent and firms.

Few cities have such a naturally occurring innovation district as Pittsburgh's greater Oakland neighborhood. It is home to two world-class research institutions, the University of Pittsburgh and Carnegie Mellon University (CMU), dozens of startup companies, co-working spaces, and the University of Pittsburgh Medical Center (UPMC).

Although it encompasses only about three percent of the city's land area, the Oakland district accounts for ten percent of residents and 29 percent of jobs, concentrated in the city's growing education and health care sectors. The 1.7-square-mile district constitutes over one-third of the entire state of Pennsylvania's university research output.



The Oakland innovation district. Photo credit: Google Earth

As with most innovation districts, Oakland is also surrounded by neighborhoods with some of the highest rates of long-term unemployment and poverty in the city. While the growth of the Oakland innovation district is creating significant economic opportunities within these communities, much more is needed to connect residents to the district through better transit, training, jobs, and shared amenities.

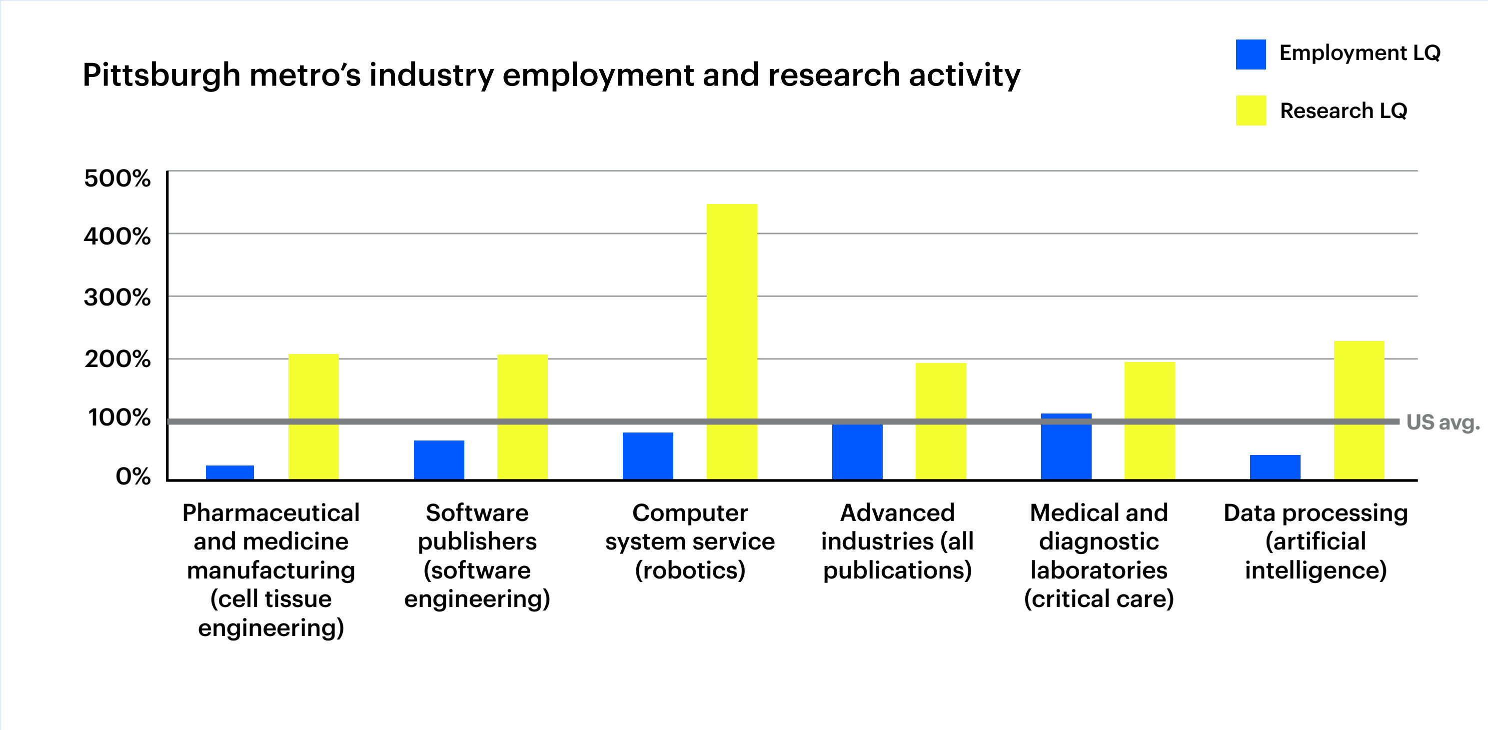
Pittsburgh possesses significant innovation assets

Pittsburgh is home to a number of advanced industries that are comprised of companies of all sizes, ranging from startups to global headquarters. Firms like PNC, UPMC, Google, Uber, Alcoa, Bayer, Allegheny Technologies, Duolingo, and hundreds of others are investing in technology and leveraging the city's innovation capacity. In broad terms, three advanced industry clusters—manufacturing, technology, and health care—represent critical pieces of the city's economic future.

Firms in these clusters rely on the strength of the university sector. On a number of metrics, the region punches far above its weight in academic activity. The metropolitan area ranks ninth among the largest 100 cities for the amount of university R&D, given the size of its economy and is a powerhouse in fields like robotics, gerontology, critical care, artificial intelligence, cell and tissue engineering, neurotrauma, and software.

At the same time, growth in the city's startup support systems—mentorship, flexible workspaces, capital, and talent attraction—are fueling a new generation of high-value firms. Startups like NoWait are leveraging the full pipeline of entrepreneurial services to attract investment and grow. Finally, many workforce development institutions in the region are improving access to the innovation economy for all workers.

However, despite its significant assets, Pittsburgh's technological strengths have not yet translated into broad-based economic opportunity or growth.



Source: Brookings and TEConomy analysis of National Science Foundation, Higher Education Research and Development Survey; BLS, QCEW enhanced file from IMPLAN; and U.S. Census Bureau. Note: LQ = regional location quotient.

Critical competitive challenges threaten Pittsburgh's opportunity

Three areas stand out as constraints to the city's economy:

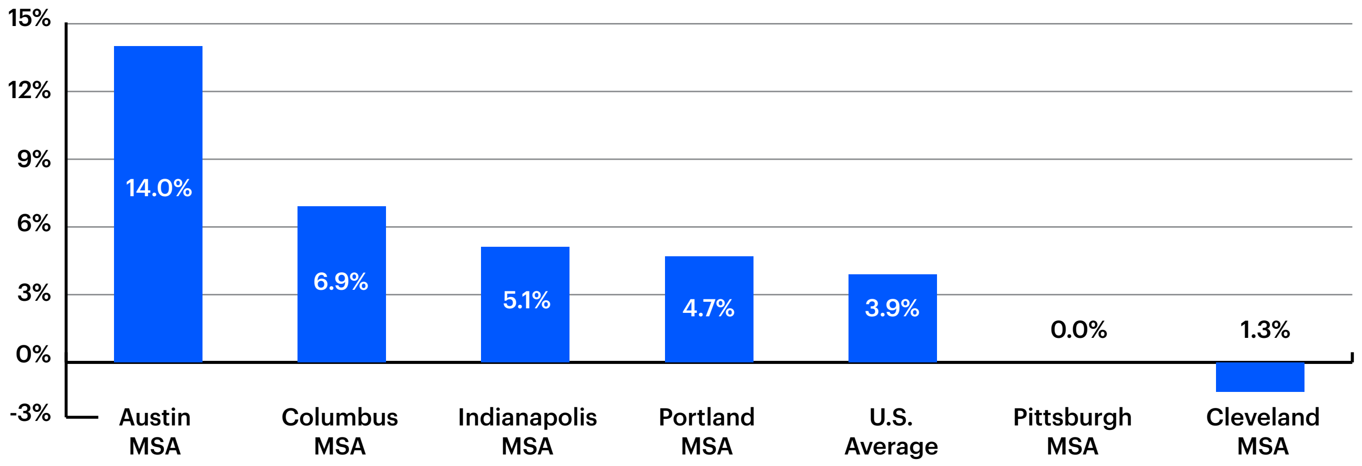
1. **The connection between research and industry strengths is weak and is dampening the region's potential.** Pittsburgh has yet to see the economic activity in advanced industries expected given its robust academic and research strengths. The difference between the level of innovation inputs (such as patents and R&D investments) and the level of economic outputs (jobs, GDP, and firms in advanced industries) is stark. For example, compared to the national average, the region performs 204 percent more research in medical science but employs 91 percent fewer workers in pharmaceutical preparations. Similarly, the region performs 225 percent above the national average in computer science research but has 36 percent fewer jobs in software and 59 percent fewer in data processing.

2. **The entrepreneurial ecosystem has yet to produce a significant number of high-growth startups.** Pittsburgh's physical and programmatic strengths are significant, yet they are insufficient to compete with Denver, Austin, Atlanta, Copenhagen and other global peers. The reality is that these cities all have serial entrepreneurs who have built high-growth companies that employ large numbers of workers. Pittsburgh has many "shots on goal" in terms of new startups, but too few are scaling to the point of being regional employment drivers. As one local entrepreneur put it, "entrepreneurship in Pittsburgh in many ways is within its first cohort. Version 1.0 was about developing capacity to generate a lot of startups. Version 2.0 will be about growth and employment generation."

3. **Demographic and skills headwinds threaten Pittsburgh's ability to create the workforce it needs to compete—both within its innovation district and beyond.** Pittsburgh faces significant demographic and competitive pressures to its innovation workforce that will stymie the region's growth if left unaddressed. Between 2009 and 2014, Pittsburgh's population remained stagnant while peer cities grew by double digits. At the same time, the average worker in Pittsburgh is older than the national average, with a quarter million people expected to retire over the next decade.

Despite the clear and present danger of a tightening labor market, not enough is being done to upskill workers

Change in total population, Pittsburgh and comparison regions, 2009-2014



Source: U.S. Census Bureau, American Community Survey, authors' calculations.

to fill the gaps. For example, 55 percent of occupations in the health care sector require less than a bachelor's degree. One CEO in the tech sector said that "75 percent of the IT jobs in the company don't require a four-year degree." And yet, the Oakland innovation district is adjacent to several poor neighborhoods—including the Hill District, Uptown, and Hazelwood—that could both benefit from jobs created in the innovation district and fill labor shortages. Other low-income neighborhoods, such as Homewood, are only a short bus ride away.

A Path Forward: Governance and Recommendations

Pittsburgh's economy is increasingly driven by innovation, yet existing initiatives and investment levels are not meeting the demands of this new economy. To address the challenges identified, greater investment and activity is needed in four broad areas: **innovation clusters, the Oakland innovation district, high-growth entrepreneurs, and workforce development.**

The road map outlined is significant and will require substantial resources and commitment of the city's leadership. Therefore, Brookings recommends launching a new initiative—the InnovatePGH partnership—to adopt and advocate a new narrative for Pittsburgh's economic future and to issue a call to action. Comprising public, private, and civic leaders, the partnership would rally new and existing resources to support the recommendations in this report and others demanded by the innovation economy.

While the recommendations called for here will likely need to be sequenced over the next decade, much can be also done in the near-term. Efforts should:

- **Build and support Pittsburgh's innovation clusters in advanced manufacturing, life sciences, and autonomous systems:** To increase the linkages between the city's research capacity and the regional economy, city leaders need to adopt a focused technology cluster approach. While there are many candidates (including financial technology ("fintech"), corporate services, and energy), three are clear first priorities given Pittsburgh's technical strengths—robotics and advanced manufacturing, life sciences, and autonomous systems.
- **Define, grow, and connect the Oakland innovation district:** To reach its full economic potential for the city and region, the Oakland innovation district needs to be defined, marketed, and better connected to the regional

economy. In particular, a comprehensive, district-wide strategy is needed to leverage the ongoing investments at CMU, Pitt, and UPMC to grow and attract firms in advanced industries. At the same time, strategies are needed to integrate Oakland with the employment centers nearby, especially toward downtown.

- **Improve the pipeline of high-growth entrepreneurs: Pittsburgh needs greater investment in its high-growth startups.** Young companies need greater access to larger firms through a First Customer Program, stronger support mechanisms around research entrepreneurs, and a global accelerator to grow and attract world-class startups in the health care sector.
- **Create a talent alliance within the Oakland innovation district:** Leveraging existing organizations, a coalition of employers, workforce development organizations, and educational institutions should identify critical occupational gaps within anchor employers, and develop and administer occupation-specific training for underskilled workers in neighborhoods adjacent to the innovation district and throughout the broader region. While a number of workforce programs already exist, the purpose would be to aggregate employment demand in hard-to-fill occupations in health care, research, and education.

Pittsburgh 2030: Innovation Job Generator or "Could-have-been"?

The actions (or inaction) Pittsburgh's leaders undertake today will determine the trajectory of the city for decades to come. At least two scenarios are possible.

In one, the city's economy is aptly described as two Pittsburghs. Here, a minority of jobs are driven by university research, small high-tech firms, and a handful of corporate research centers, while the broader economy (which makes up the majority of workers and families) consists of local services and traditional low- and mid-level manufacturing jobs that, like in much of the Rust Belt, are increasingly automated or outsourced. In this scenario, income and unemployment will vary significantly depending upon the neighborhood.

But in a more dynamic scenario, Pittsburgh's broader economy flourishes. The lines between academic research and industry innovation are indistinguishable as major employers in health care, finance, corporate services, and manufacturing collaborate, adopt, and nimbly deploy technology to stay ahead of global competitors. As such, high-value exports of both goods and services expand, creating a reliable tax base and pool of high-wage jobs. Well-resourced and coordinated education and workforce programs identify and attack unemployment in high-poverty neighborhoods. Getting a lifelong job in a factory with a high school education is as unrealistic in the future as it is today—but unlike today, everyone has options. In this scenario, the innovation economy is Pittsburgh's economy and all benefit.

Both scenarios are realistic. The outcome will be determined by the investments made today.

Section 1: Introduction

Pittsburgh is nothing if not a city of revivals. Few cities have experienced the economic upheaval of Pittsburgh in the 1970s and 1980s—and came back. Situated at the intersection of the Allegheny, Monongahela, and Ohio rivers, in the post-War decades Pittsburgh was both figuratively and literally a chief arteria of American manufacturing. During the country's industrial heyday, the city swelled in population and income. But by 1980, global economic forces had shuttered much of the U.S. steel industry, and 75 percent of Pittsburgh's steelmaking capacity simply vanished. With 130,000 manufacturing jobs lost and unemployment at 18 percent, Western Pennsylvania effectively experienced a second Great Depression.[1]

Today, Pittsburgh looks neither as it did in its industrial glory nor as it did during its subsequent demise. The economy has shifted from low- and moderate-value production to technology-driven services and high-value, advanced manufacturing. In 2016, the city employed 115,500 workers in health care, and the metropolitan area performs 230 percent of the national average in university research for its size. The competitive advantage of the region is no longer its rivers and raw materials but high-skilled workers, world-class research institutions, and advanced manufacturing. These considerable assets place Pittsburgh in the ranks of the international innovation cities now competing for a suite of new technologies set to redefine the global economy.

Technology shapes economies in long waves of innovation.[2] It can take decades for scientific discovery to translate into new products and services, but the transition from niche markets to global ubiquity can occur rapidly. For example, it took 50 years for basic semiconductor research to produce the first smartphone, but less than a decade for smartphones to spread to 2.16 billion users. The McKinsey Global Institute predicts that roughly a dozen technologies, including genomics, energy storage, and automation, are at the cusp of adoption and by 2025 could constitute one-third of global GDP.[3] But as with all disruptive technologies, there will be winners and losers. Economist Joseph Schumpeter observed that innovation is usually accompanied by "creative destruction," which shifts the competitive balance sheets of firms, cities, and nations.[4] This process played out in the 20th century, when the biggest winners were those that got in on the ground floor of technology platforms that redefined the global economy—from industrial centers like Detroit to finance centers like New York City and London and to information technology hubs like Silicon Valley and Boston.

As in the past, the cities at the forefront of these economy-shaping technologies will benefit dramatically, attracting the global capital and talent that will allow firms within the region to grow and scale up. This growth and investment will in turn lead to more and better-paying jobs for cities with higher gross metropolitan product, and increased revenues that can be reinvested in education, workforce development, infrastructure, and neighborhood revitalization.

Pittsburgh is among several dozen global cities that have the institutions, innovative capacity, and core science and technology competencies to compete for leadership in some of these next-generation technologies. But while the opportunity is there, success is by no means a foregone conclusion. Despite its national reputation as a Rust Belt renaissance city, Pittsburgh's technological strengths have not yet translated into broad-based economic opportunity or growth. Success stories are still anecdotal and have not aggregated into substantial employment, entrepreneurship, output, or exports.

Indeed, the evidence suggests that Pittsburgh faces competitive headwinds that position it as an underdog in this elite race. For example, in 2016 the city had seven percent fewer jobs in high-wage, high-tech advanced industries than it did in 2000.[5] In fact, if the Pittsburgh region had jobs equal to its research investments, it would employ 9,000 more in the software industry and 5,500 more workers in drug development, not to mention many workers whose positions would follow along from this employment.[6]

Autonomous systems and Pittsburgh's play

Autonomous systems—information technology that enables machinery to function independently of a human operator—are a classic example of a general purpose technology that can influence a cross-section of industries due to its widespread application. The most visible application of autonomous systems is within self-driving automobiles. The McKinsey Global Institute estimates that autonomous vehicles (AVs) could have an economic impact of $1.9 trillion by 2025 and reduce the 1.5 million projected deaths from car accidents.[7] But autonomous systems also hold the potential to reshape agriculture, manufacturing, wholesale, defense, and textiles. For example, health care—one of Pittsburgh's growth sectors—is predicted to be a major home for robotics, artificial intelligence, and other forms of autonomous systems that monitor patients, provide pharmaceutical support, and improve decision making.[8]

With self-driving cars capturing the interest of the public, Pittsburgh has become the face of AV technology. This reputation is in part due to Uber's relationship with Carnegie Mellon University (CMU) and the company's decision to make Pittsburgh the testbed for a fleet of autonomous ride-sharing vehicles. Adding to the momentum, Ford Motor Company recently invested $1 billion in Argo AI, a startup with roots in CMU and the National Robotics Engineering Center. As autonomous technologies become a staple of the global economy, there is the potential for broad-based employment opportunities in Pittsburgh if it becomes the global knowledge center of automation in manufacturing, after-market services, repair, management consulting, and finance. Associate degree programs like mechatronics (which blends electrical and mechanical engineering), offered at the Community College of Allegheny County, give students an opportunity to repair and perform maintenance on computer-operated machinery and other autonomous systems that will soon be on every street and in every home, office, and factory.

Without a robust platform of jobs at all skill levels, the city's significant research and technical strengths will fuel only a small portion of the region's economy and leave many workers and families behind. Yet Pittsburgh has everything needed to translate its global research enterprise into a groundswell of economic activity that reaches into communities across the region.

The goal of this study is to present a tailored and specific road map for how city leaders can create jobs and firms around Pittsburgh's innovation strengths.

Today, Pittsburgh is once again at the precipice of a new competitive opportunity. In the 1980s, the city was on the losing end of shifts in the global economy. Now, in the modern, innovation economy, the city can choose its own fate. Success or failure will be determined by the speed and scale of actions taken by public, private, and civic leaders.

Section 2: Pittsburgh's innovation district

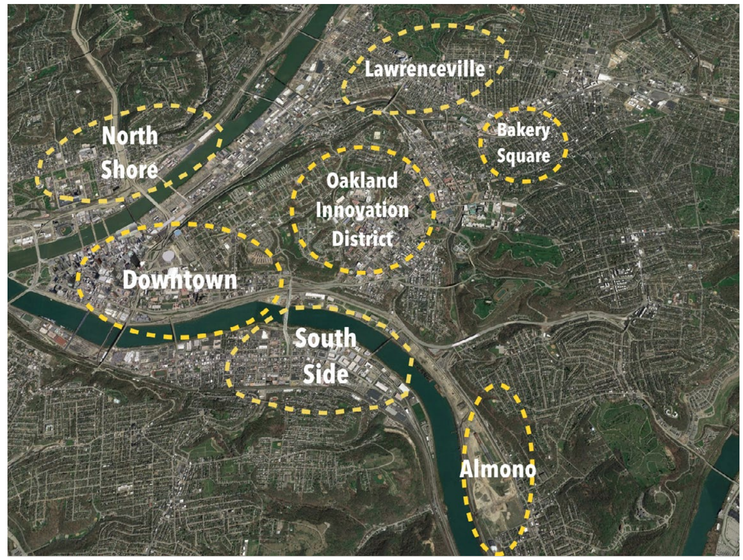
Just as global technology and market forces have created new opportunity for Pittsburgh, the spatial geography of the knowledge economy has also changed. Cities in both the United States and abroad are witnessing the emergence of dense hubs of economic activity where innovation, entrepreneurship, creativity, and placemaking intersect. At the advanced, research-led end of the economy, *innovation districts* are developing around anchors such as universities, medical centers, and large firms, along waterfronts, and in urbanizing science parks.[9] Strong in sectors such as the life sciences, technology, and engineering, these districts cluster and connect research institutions and technology firms with a rich entrepreneurial ecosystem of startups, venture capital firms, and co-working spaces. They also have good transit and walkability; a diversity of arts, culture, and other amenities; and a strong sense of place and community. Innovation districts are rarely the sole neighborhood in which innovation occurs; instead, they serve as a central hub to connect the many corridors of activity throughout a city.

Few cities are home to such a naturally occurring innovation district as the greater Oakland neighborhood. It is home to two world class research institutions, the University of Pittsburgh and Carnegie Mellon University (CMU), dozens of startup companies (NoWait, Peptilogics) and co-working spaces (Avenu, Ascender), and the University of Pittsburgh Medical Center (UPMC). South Oakland, along the Monongahela River, is home to the Pittsburgh Technology Council, CMU and Pitt research facilities, and large scientific and technology firms such as Thermo Fisher Scientific. Companies and research centers have gravitated toward CMU and Pitt, and investments in space suitable for corporate partners like CMU's Collaborative Innovation Center and co-working spaces have attracted small-scale industry presences that are largely focused on partnering with the universities.

The Oakland innovation district

The greater Oakland district is roughly three percent of the city's land area but represents ten percent of residents and 29 percent of jobs, concentrated in the

The Oakland innovation district. Photo Credit: Google Earth



Pittsburgh's innovation neighborhoods: Photo Credit: Google Earth

city's growing education and health care sectors. The 1.7-square-mile district constitutes one-third of the entire state of Pennsylvania's university research and development (R&D) output.[10]

Innovation districts—even those with the natural density and capacity of Oakland—are not islands. The value of an innovation district is defined by the interplay between district anchors, firms, and startups and job creation in the region. Therefore, the innovation assets adjacent to a district's borders are just as important as the institutions within the district. To the northeast of Oakland is Chatham University and Bakery Square, home to Google and Pitt's Human Engineering Research Laboratories and UPMC Enterprises. To the northwest is Lawrenceville, anchored by CMU's National Robotics Engineering Center (NREC) and perhaps the fastest-growing cluster of robotics startups in the country. To the south is the 178-acre Almono brownfield site, which is being redeveloped to potentially serve as one of the nation's largest autonomous vehicle testing sites. Southeast of the district is downtown Pittsburgh, with over 45,000 jobs and national headquarters like PNC Bank, Highmark, PPG Industries, and U.S. Steel.

Pittsburgh's innovation neighborhoods

The links between the district and the broader innovation economy go far beyond geographic proximity. Its academic and technical strengths are feedstock to the regional economy, whether through CMU's connection to GE's Center for Additive Technology Advancement near the airport or Pitt's research that is translated into patient care and jobs at UPMC's dozens of regional hospitals and clinical care facilities. To ensure economic success for the whole region, the innovation district is a staging ground for programs, efforts, and investments that will need to be deployed across the metro area.

As with most innovation districts, Oakland is surrounded by some of the city's poorest neighborhoods—the Hill District, Uptown, and Hazelwood have some of the highest rates of long-term unemployment and poverty within the city. While the growth of Oakland is creating significant economic opportunities within these communities, much more is needed to connect residents to the district through better transit, training, jobs, and shared amenities.

Section 3: Pittsburgh possesses significant innovation assets

Pittsburgh has a strong starting position to challenge international competitors and attract global markets, talent, capital, and companies.

Pittsburgh is a growing hub of high-value industries with significant technical strengths.

Pittsburgh has a number of advanced industry clusters that represent both critical high-value firms and broad employment opportunities in a cross-section of the economy. Based on regional specialization, growth rates (locally and nationally), employment levels, wage rates, and supply chain context in the region, we identified 11 export-oriented advanced industries that broadly fall into three clusters: advanced business and health services, manufacturing, and technology (see Appendix A). These clusters include firms like PNC, UPMC, Google, Uber, Alcoa, Bayer, Allegheny Technologies, Duolingo, and hundreds of others. Since the end of the recession, these advanced industries grew by 8.4 percent, nearly double Pittsburgh's overall private-sector growth rate of 4.4 percent. Put another way, Pittsburgh has a strong and growing presence in the sectors that will drive job growth in the coming decades.

Despite the city's reputation as an "old economy" town, advanced manufacturing stands out as a critical economic driver. As of 2015, Pittsburgh was home to over 103,000 jobs in automation and industrial machinery, metals and metal processing, chemicals, engineering services, electronics, and energy. These industries represent 67 percent more jobs than expected given the size of the Pittsburgh economy. Post-recession job growth in advanced manufacturing reached 11.3 percent, 2.5 times the pace of the Pittsburgh economy as a whole. Moreover, productivity, a key measure of technology deployment and the value of production, is 7 percent higher in Pittsburgh's advanced manufacturing industries than the national average.

Outside of manufacturing (but related to its success), the city has become a hotbed of domestic direct investment from technology companies seeking access to high-end engineering and computer

Table 1: Summary Employment Metrics, Pittsburgh (MSA) Industry Clusters, 2015

Advanced Industry Clusters	Pittsburgh MSA Employment, 2015	Employment Change, 2009-15	Location Quotient, 2015	Avg. Annual Wage, 2015
Total Private Sector	986,838	4.4%	1.00	$52,829
Total, Advanced Industry Clusters	325,958	8.4%	1.33	$76,270
Automation and Industrial Machinery*	6,909	6.3%	2.61	$70,590
Chemicals, Polymers and Other Non-Metal Materials	13,177	10.4%	1.83	$59,416
Computing, Networking, Information Services and Internet Applications	17,474	46.4%	0.73	$95,367
Corporate Services	47,596	18.5%	1.45	$126,131
Electronics Manufacturing	5,928	-4.0%	1.26	$68,723
Energy	18,732	32.7%	1.42	$96,042
Engineering, Commercial Research and Technical Services	29,766	18.3%	1.46	$86,227
Financial and Insurance	54,691	1.8%	1.15	$79,745
Health Services	93,601	0.8%	1.33	$46,739
Medical Technology	8,809	1.1%	0.97	$71,319
Metals & Metal Processing	29,276	-0.4%	2.09	$60,906

*Automation & industrial machinery is industrial manufacturing, not autonomous systems or robotics.
Source: Brookings and TEConomy Partners analysis of Bureau of Labor Statistics, QCEW; enhanced file from IMPLAN.

science talent. Google began operations in Pittsburgh to work with CMU faculty at CMU's Collaborative Innovation Center with other tech giants like Intel, Apple, and Disney. The company is now located in Bakery Square employs over 500 world class engineers, coders, and scientists. Uber's presence in the city originated with a partnership with CMU's NREC, and the largest deployment of Uber's self-driving car is now being tested on the streets of the city.

Finally, the city has growing strengths in health care, driven in large part by UPMC. In clinical excellence, UPMC is widely recognized as one of the nation's top hospitals, ranking 14th in the latest *U.S. News & World Report* standings; its medical specialties are ranked in the top 20 nationally.[11] While the city does not have a robust life sciences cluster (discussed below), the excellence of UPMC attracts patients well beyond the Pittsburgh region and helps explain why health services in the region are 33 percent more concentrated as a share of total private-sector employment compared to the nation as a whole. UPMC and its partnership with Pitt represent an unique asset to the region, one that combines an insurance product, a global health system, and a top-tier life sciences research university.

These advanced industry clusters—manufacturing, technology, and health—represent critical pieces of Pittsburgh's economic future

Pittsburgh hosts substantial academic and research strengths in areas transforming the economy

Perhaps the strongest asset in Pittsburgh's innovation economy is the size, quality, and scope of research. On a number of metrics, the region punches far above its weight. Beginning with size, the region is home to over a dozen colleges and universities and over $1 billion in university R&D. The metropolitan area ranks ninth among the top 100 cities for the amount of university R&D given the size of its economy, and it receives 230 percent its expected share in research dollars, with significant strengths in specific areas (see Figure 1). The metropolitan area also produces 273 percent of its share of scholarly publications, outperforming the national average in fields like robotics, gerontology, critical care, artificial intelligence, cell tissue engineering, neurotrauma, and software.

These areas of research strength aren't just relevant to academic rankings; they align well with economic opportunity. An analysis of the region's academic patenting identifies several core areas of university research strengths spanning fields such as immunology/immunotherapy, cell and tissue engineering, and semiconductors, as well as cross-disciplinary bridging connections of the biotech/medical innovation space to data analytics, image analysis, and materials technologies (see Appendix B for a full description). These technology categories are important to a number of rapidly expanding industries, specifically in life sciences, advanced manufacturing, and automation and software.

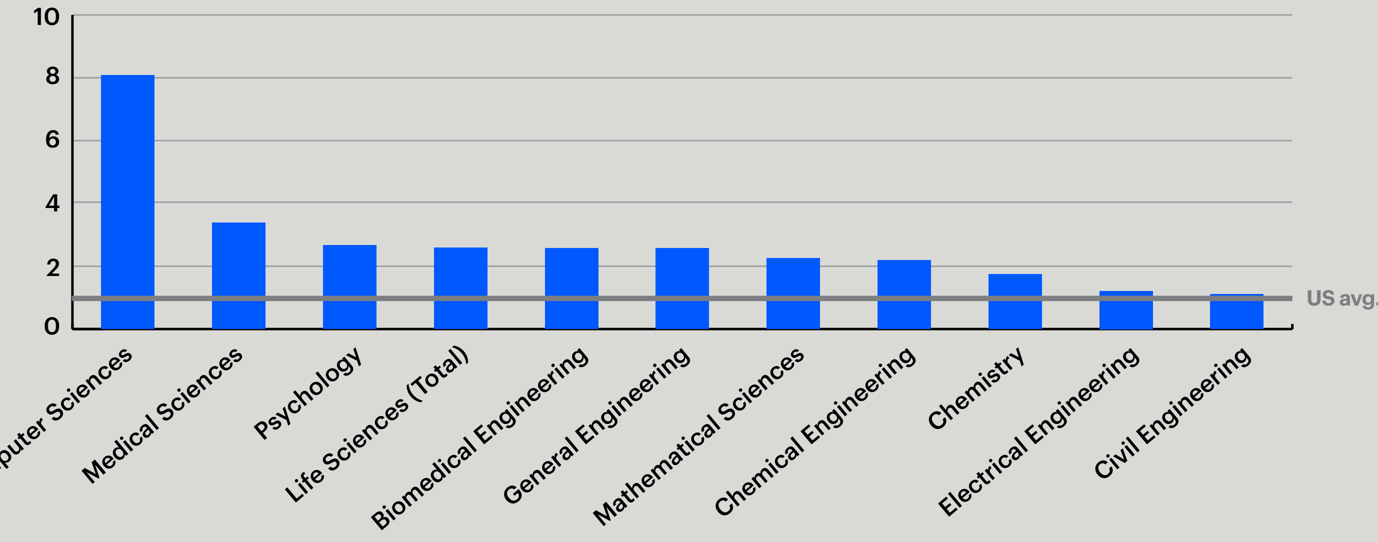
Located in the heart of the innovation district, the University of Pittsburgh and Carnegie Mellon comprise the lion's share of the region's academic strengths in medical, engineering, and computer science disciplines.[12] These strengths are already translating into economic opportunities.

The Advanced Robotics Manufacturing Innovation Hub

In January of 2017, an independent, public-private partnership institute founded by Carnegie Mellon University (CMU) was awarded the Advanced Robotics Manufacturing (ARM) Innovation Hub by the Department of Defense. Funding for ARM is set for just over $250 million, with $80 million awarded by the Department of Defense and an additional $173 million in matching funds committed from a variety of partner organizations, including industry, state and local government, universities, and nonprofit organizations. ARM is positioned to leverage the strengths of CMU and the broader Pittsburgh region in artificial intelligence, autonomy, 3-D printing, and other emerging technologies to make industrial robots more affordable and adaptable for businesses.

Though headquartered in Pittsburgh and offering a 50,000-square-foot facility near CMU's National Robotics Engineering Center, ARM is a national consortium. It involves 123 industrial partners, 40 academic and academically affiliated partners, and 64 government and nonprofit partners, located in over 30 states. ARM will involve a network of eight regionally based centers for robotics prototyping and testing and access to many manufacturing shared-use facilities of its partners. It will bring a specific focus on the national challenges in advancing robotics within the aerospace, automotive, electronics, and textile sectors. While an unquestionable asset, given ARM is a national consortium, for it to have an oversized impact on the region, specific Pittsburgh-centric wraparound strategies are essential.

Figure 1: University R&D expenditures per metropolitan population, 2015



Source: Brookings and TEConomy analysis of National Science Foundation's Higher Education Research and Development Survey, 2015.

Pittsburgh stands out as a leading region in biomedical research, innovation, and clinical excellence. Overall, academic research expenditures in medical sciences are 350 percent the national average: the University of Pittsburgh was the fifth highest recipient of National Institutes of Health funding, the gold standard of biomedical research, in 2016. And academic strengths at Pitt are well positioned to intersect with new and growing industry activity, including immunotherapy (cancer treatments), aging, precision medicine (genetic-based medicine), and brain-computer interface (through which the brain electronically controls mechanical systems such as wheelchairs). Each of these areas represents multibillion-dollar global markets.

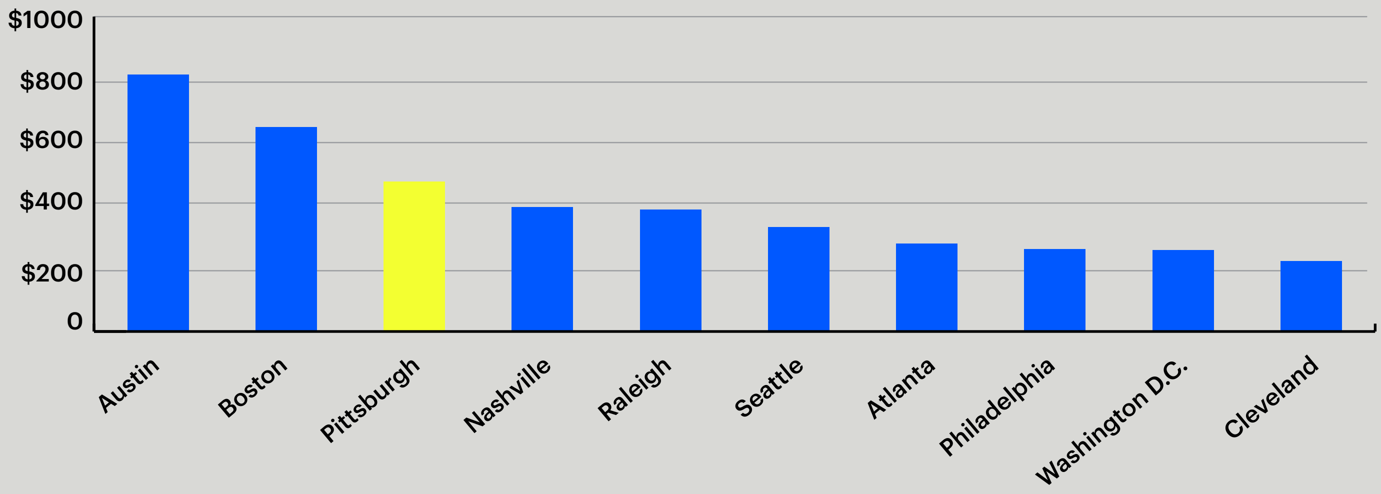
Within advanced manufacturing, both Pitt and CMU have developed strengths in metals-based additive manufacturing and are active participants in AmericaMakes, the national additive manufacturing innovation institute based in Youngstown, Ohio.

The region's strength in additive manufacturing also extends outside of academia—Catalyst Connection, Pittsburgh's manufacturing extension partnership, has supported the Additive Manufacturing Consortium, made up of 70 local businesses and organizations.

NREC, an operating unit within CMU's Robotics Institute, is one of most prestigious robotics R&D organization in the world, and it is the primary reason the region attracted the ARM Innovation Hub (see box). Finally, the region is a powerhouse in digital technologies like machine learning. CMU's computer science and computer engineering programs rank first and second, respectively, nationally.[13] Catalyst Connection has a number of successful partnerships with the universities and helps connect their technical capacity with small and medium-sized manufacturers in Pittsburgh.

The scientific, academic, and technical strengths within Pittsburgh are creating powerful platforms

Figure 2: University R&D expenditures per metropolitan population,Pittsburgh and selected regions, 2015



Source: Brookings and TEConomy analysis of National Science Foundation's Higher Education Research and Development Survey, 2015.

that bridge industry clusters. Advances in robotics, additive manufacturing, and data analysis in health care are increasingly relevant for Pittsburgh's major employment drivers such as finance, insurance, and clinical care. A good example of this synergy is the Health Data Alliance, a partnership between UPMC, Pitt, and CMU that leverages each institution's unique competencies in clinical care, medical research, and computer science to revolutionize data analytics in health care.

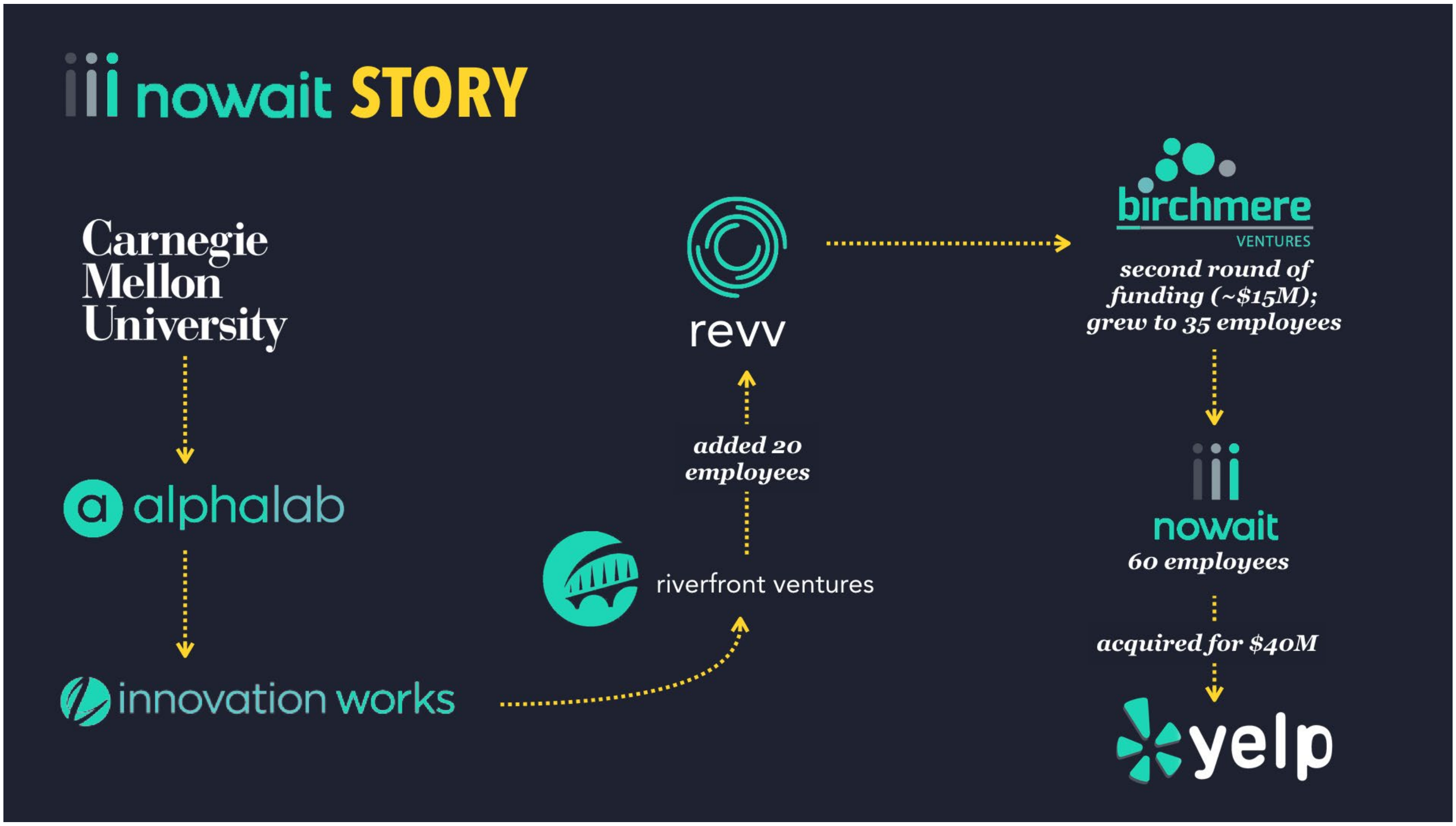
If fully leveraged by firms, corporate research centers, and entrepreneurs, these academic strengths offer the opportunity to move Pittsburgh's economy up the value chain—creating sustainable jobs, industries, and firms in next-generation technologies.

Pittsburgh's historic academic and philanthropic partnerships

Pittsburgh has a long history of engagement between philanthropy and universities, and the partnerships created have supported a host of research activities that has become pivotal to the Pittsburgh economy. Foundations in the city seem to view technology-based economic development as a critical component of their social missions and invest accordingly.

According to interviews at Carnegie Mellon University, foundation grants were instrumental in starting fields of study such as machine learning, computational finance, and robotics. More recently, local philanthropic investments were critical to attracting the ARM Innovation Hub.

Similar support in the past had enabled efforts like the Pittsburgh Life Sciences Greenhouse and other economic-based activities in the life sciences. Philanthropic investment has also supported the testing of technology through brownfield redevelopments such as the Almono site. Investments in smart transportation and smart grid (DC AMPS, etc.) initiatives have created the necessary infrastructure to move robotic, sensor, and automation technologies out of the lab and into the city. Finally, civic capital in the form of seed and gap funding for academic entrepreneurs has been critical for the region in supporting research-based startups. These include sizeable investments in accelerators and incubators like Innovation Works, Idea Foundry, Ascender, and Avenu (formerly StartUptown), and in university infrastructure such as Pitt's Innovation Institute and CMU's Swartz Center for Entrepreneurship.



Nowait illustrates the Pittsburgh entrepreneurial ecosystem. Photo credit: Brookings.

The city is home to a growing startup ecosystem

The ability to create and grow young companies is a linchpin of economic prosperity for any city, and Pittsburgh is rapidly improving its startup capacity. The region has a number of strong support institutions including university-based programs, Innovation Works, and a host of others. Research entrepreneurs are also a critical strength of Pittsburgh. Between 2014 and 2016 the city had over 10 times the number of Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) recipients—a good proxy for the strength of research-based startups—as the national average. Finally, in health care, UPMC Enterprises, the for-profit subsidiary of UPMC, is a powerhouse investor in innovation and provides substantial opportunity to build, attract, and acquire health care startups. In 2016, UPMC Enterprises invested over $130 million

Nowait shows the connections within Pittsburgh's startup ecosystem

Nowait, a restaurant wait list management app, offers a good example of how the different points in the startup pipeline have come together to improve the overall ecosystem for entrepreneurs in Pittsburgh. The company, founded by Robb Myer, a CMU graduate (who is now an entrepreneur-in-residence at the Swartz Center), went through the AlphaLab accelerator and received seed funding from Innovation Works. It leveraged office space at Avenue (formerly StartUptown and Revv) in the Oakland innovation district and benefited from tax incentives and other support programming through its location in Urban Innovation 21, a Keystone Innovation Zone, that was directly supported by the Urban Redevelopment Authority of Pittsburgh. Nowait received venture funding from Pittsburgh-based Birchmere Ventures and Riverfront Ventures. In March 2017, Yelp acquired Nowait for $40 million and has integrated the company's software into its online platform. The company continues to be operated out of Pittsburgh.

in new technologies and startups, and it has spun off successful firms like Evolent Health, which went public in 2015 with a market capitalization of over $1 billion.[14] However, the company's headquarters and majority workforce are now in Virginia, a relocation that highlights the need to capture the growth of startups locally.

Innovation Works operates two accelerator programs, AlphaLab and AlphaLab Gear (for hardware companies). AlphaLab was ranked the sixth best accelerator in 2014 by researchers at Rice University, the University of Richmond, and the Massachusetts Institute of Technology. Innovation Works and other organizations like Pittsburgh Life Sciences Greenhouse also provide early stage capital to local entrepreneurs.

Access to private-sector capital has become easier. Pittsburgh was once mostly ignored by coastal investors; today, a number of the city's top startups have successfully attracted investment from outside the region. As an analysis by Ernst and Young and Innovation Works found, the Pittsburgh region ranked fifth in the number of deals per capita in 2016.[15] And despite not having the reputation as a hotbed for life sciences startups, Pittsburgh has had success in generating venture-backed life sciences companies with 50 attracting over $400 million in investments from 2009 to 2015.

Finally, over the last several years the city has become an attractive destination for young workers by offering a number of new amenities, art venues, and an improved food culture. While often ignored by economists, these lifestyle attributes are essential to attracting and retaining talent and entrepreneurs. The Oakland innovation district, for example, has become home to a dense blend of research, amenities, and co-working spaces. Across the city entrepreneurial space and programming are expanding and include Alloy26, Ascender, IdeaFoundry, UpTown, Coterie Company, Urban Innovation 21, the Beauty Shoppe, the Blast Furnace, the newly formed Pittsburgh Robotics Network, and many others.

The region offers a number of training programs that position workers for the innovation economy

The Pittsburgh innovation economy includes far more than the advanced research sector and the high-skilled workforce most associated with it. The development of new therapies at Pitt, which are absorbed and deployed among patients by UPMC and other hospitals in the region, creates demand for middle-skilled occupations like medical transcriptionists, nursing assistants, and a host of others. The region's innovation economy now depends on a host of occupations across the education spectrum, specifically occupations requiring less than a bachelor's degree. For example, half of the science, technology, engineering, and math (STEM) occupations in the region require less than a four-year degree.[16]

Many institutions in the region are beginning to position themselves as conduits between the business community and the workforce. The Allegheny Conference on Community Development's current three-year agenda prioritizes identifying in-demand occupations and connecting workers to jobs. Recognizing the region's diverse strengths and opportunities in the energy and manufacturing sectors, the Energy Innovation Center (EIC) is focused on developing and demonstrating technology, incubating businesses, and aligning workforce development and education, all to support emerging clean and sustainable energy technology and markets. With 200,000 square feet in a renovated career and technical education high school in the Lower Hill District and a vibrant, diverse set of co-located tenants, the EIC is a living laboratory for industry-driven, innovative education and training programs. Finally, the local workforce investment board, Partner4Work, has increased its connection between businesses and jobseekers and positioned itself as an important source of programming and labor market analytics.[17]

In many ways, the Oakland innovation district offers a unique microcosm for the demands of the broader region's advanced economy, particularly in technology and health care. An analysis by Partner4Work finds that four of the five highest in demand skills in the metropolitan area are related to health and technology, including patient care, cardiopulmonary resuscitation (CPR), treatment planning, and software development. This makes sense, given that the top-demanded occupation is registered nursing.[18] With its health care orientation, the innovation district has many well-paying, middle-skill occupations: over 20,000 hospital and clinician jobs pay above the median Pittsburgh wage but require less than a four-year degree.

In sum, the quality of Pittsburgh's starting position is evidenced by its mix of advanced industry firms, academic core competencies, a burgeoning startup ecosystem for entrepreneurs, and a growing workforce capable of building the city around innovation. Despite these strengths, the city has yet to fully maximize its innovation capacity to benefit of the whole economy. A series of significant challenges remain barriers to growth.

Section 4: Critical competitive challenges threatening Pittsburgh's growth opportunity

In order for cities to create and grow high-value goods and services, they must seamlessly align their most competitive assets. Some cities are home to technology headquarter firms (Dell in Austin, Amazon in Seattle), others have dense research parks that cluster small, medium, and large high-value firms (Texas Medical Center in Houston), while others leverage massive venture capital networks and financial centers (Boston and New York City). And some cities have a critical mass in all of the above (San Francisco, London). But all global innovation cities have identified their unique strengths and coordinated to leverage assets and grow.

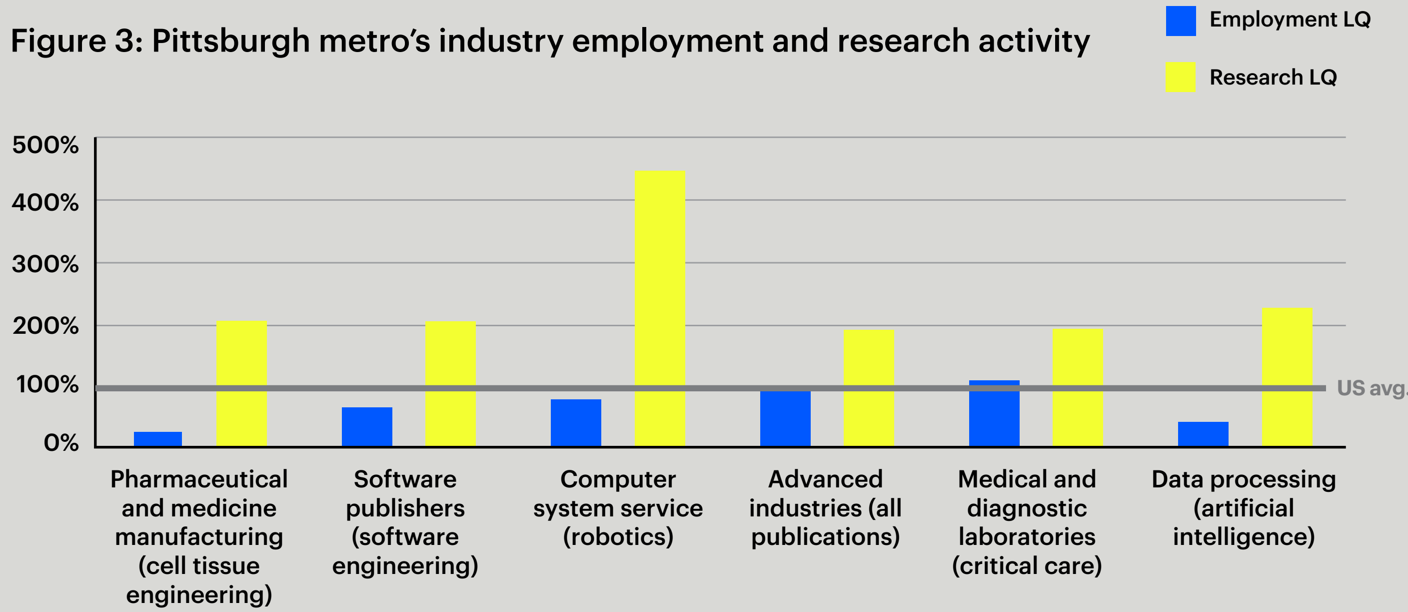
Pittsburgh's strengths are within its academic research, corporate headquarters, flagship technology firms, and high-tech entrepreneurs—all of which are aided and abetted by a robust and economic-minded philanthropic sector and a rich ecosystem of civic institutions. However, to date, these assets have not sufficiently aligned to generate significant and broad economic activity. And while the city has a number of highly visible economic success stories that have propelled it into the national spotlight, firm attraction, retention, and growth in next-generation technology clusters remain anecdotal and are not borne out in employment statistics. Put another way, the city's technical capacity has not yet fundamentally shifted the trend line of Pittsburgh's economy.

Thus, while the region starts from a solid position, it has critical weaknesses in the race.

The connection between research and industry strengths is weak and is dampening the region's potential

Pittsburgh has yet to see the economic activity in advanced industries one would expect given its robust academic and research strengths. The difference between the level of innovation inputs (patents, R&D investments, etc.) and the level of economic outputs (jobs, output, and firms in advanced industries) is stark.

Figure 3: Pittsburgh metro's industry employment and research activity



Source: Brookings and TEConomy analysis of National Science Foundation, Higher Education Research and Development Survey; BLS, QCEW enhanced file from IMPLAN; and U.S. Census Bureau. Note: LQ = regional location quotient.

The gap between academic prowess and industrial activity is most pronounced in the life sciences and information technology sectors. In each of these areas the region punches far above its weight in core academic competencies, but it significantly underperforms in industry presence and employment. For example, in health care, the region performs 204 percent more research in medical science but employs 91 percent fewer workers in pharmaceutical preparations compared to national averages. Within information technology, the region performs 225 percent above the national average in computer science research but has 36 percent fewer jobs in software and 59 percent fewer jobs in data processing. While the advanced manufacturing industry is highly specialized and innovative in Pittsburgh and universities are world-class leaders in advanced manufacturing technologies, regional industry has yet to fully embrace that future.

As Figure 3 shows, there are at least a half dozen areas across these sectors that exhibit a pronounced disconnect between core technical competencies (evidenced by a high research activity per capita, compared to the national average) and economic activity (a low employment share, compared to the national average).

Within each of the region's prime technology strengths there are large gaps between technical competencies and industry outcomes. Left unaddressed, these deficiencies will reduce Pittsburgh's ability to compete on a global stage and prevent the region from realizing its job creation potential. Within life sciences, the lack of significant industry presence—either in production or research—limits the impact of academic research. Manufacturing faces different issues: large firms exist in the region and are involved in patenting and innovation, but the supply chain is thin, with many small and medium-sized firms having little access to the technologies they require. Finally, a number of research-intensive information technology, machine learning, and automation firms are located in Pittsburgh—predominately because of CMU—but the overall software sector is small and these technologies are yet to be fully leveraged in adjacent clusters such as finance and manufacturing.

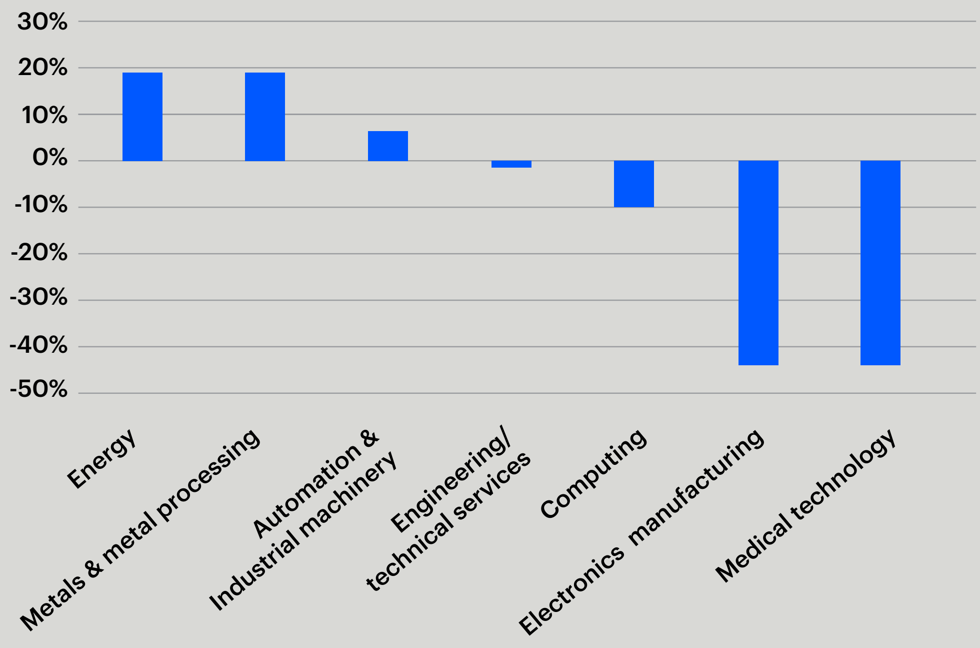
In the industrial life sciences (outside of clinical care, where the region boasts tens of thousands of health services jobs), industries such as pharmaceuticals, medical devices, and commercial research and testing fail to stand out on the national stage. Low firm and employment numbers are evidence of larger concerns. To begin with, productivity—the amount of economic value produced per worker—is well below the national average. Life sciences/medical technology firms in Greater Pittsburgh are 57 percent as productive as their peers across the country. In other words, for every dollar generated by the average U.S. medical technology worker, a Pittsburgh worker generates roughly half that. These stark figures suggest the life sciences industry is not creating or retaining high-value, innovation-driven products. For example, Cohera Medical, a medical device company that spun out of Pitt, relocated to Raleigh, N.C. in 2016 after raising $50 million in venture capital and receiving Food and Drug Administration (FDA) approval.[19]

Despite the health research base, major life science corporations have not flocked to the region. The opportunity for Pittsburgh is based in commercializing its significant base of research, especially in areas of research excellence. A missing component noted in recent gap analysis studies of Pittsburgh's life sciences industry is the lack of a champion for the industry and the lack of a comprehensive cluster organization to accelerate growth.[20]

Pittsburgh's advanced manufacturing sector—including robotics, energy, metals, etc.—is home to a number of large, highly innovative companies like Alcoa, PPG, and Eaton that lead their industry in technology adoption and creation. However, here there is a mismatch between industry and academic patent expertise. An analysis of the region's patent portfolio shows that industry has distinct areas of focus in machine tools, polymers and coatings, electrical switches, and spectrometry, while universities have distinct patent strengths in biosciences technology areas. On the positive side, there are clear bridging technologies (patent areas that link strengths in universities and industry) that are highly relevant to "smart manufacturing"—the use of information technology and data within the production process. Technologies that link industry and academic strengths include pattern recognition, sensors, and image analysis (see Appendix B for a full explanation of the patent analysis). These technologies are core competencies for CMU, but firm interviews and a review of patent citations[21] suggest that these technologies are not being broadly adopted across the manufacturing sector.

Some connections between industry and research are extremely strong in the region. For example, GE has set up its national additive metals manufacturing research center to, in part, take advantage of CMU's research in 3-D printed metals. Yet these connections exist among corporate research centers like GE, Uber, and Google and among small, extremely high-tech research firms in robotics, automation, and software, but not very far beyond.

Figure 4: Productivity of select advanced industries in Pittsburgh as a percent of the national average



Source: TEConomy analysis of IMPLAN Input/Output model for Pittsburgh MSA.

For example, the region's manufacturing supply chain purchases 25 percent less in computer and information services from local technology suppliers than firms do nationally, suggesting a disconnect between the city's high-end technology firms and the manufacturing sector.[22] This finding echoes concerns from interviews with industry and university leaders about the level of collaboration between the region's manufacturing sector (particularly among small and medium-sized firms) and the city's technology anchors. One reason for the disconnect between manufacturing and technology is a lack of broad, private-sector technology firms. At three-fourths the national average, the information technology (IT) sector is not large enough to provide the diverse services needed to other sectors. Moreover, the productivity of the overall IT sector is below the national average (see Figure 4). Given that the city, and the innovation district in particular, are home to leading global companies like Google, this finding may seem counterintuitive. But despite a host of extremely high-value technology companies, the majority of Pittsburgh's IT sector performs reasonably low-value services like database management. There is a "missing middle" between the city's small but high-value technology and robotics firms and the broad lower-value sector.

The entrepreneurial ecosystem has yet to produce a significant number of high-growth startups

While Pittsburgh has made substantial strides within its entrepreneurial ecosystem over the past decade, the city's current physical and programmatic strengths are woefully insufficient for competing with tier-two cities like Denver, Austin, Atlanta, and others. These cities have serial entrepreneurs who have built high-growth companies that employ large numbers of workers. Pittsburgh has many new startups, but too few are scaling to the point of being a sustainable feature for economic development. As one local entrepreneur put it, "entrepreneurship in Pittsburgh in many ways is within its first cohort. Version 1.0

was about developing capacity to generate a lot of startups. Version 2.0 will be about growth and employment generation."

This observation is borne out in the data. Pittsburgh ranks 27th out of 40 benchmark cities for high-growth startups, and the city's new firm density rate is 5.3 percent compared to 8.0 percent nationally.[23] Pittsburgh's fastest-growing companies are not yet drivers of large-scale employment. The metro area had only six firms with over 100 employees in *Inc.* magazine's *5000,* a list of the nation's 5,000 fastest-growing firms, far below its expected level given the size of the economy.[24]

While Pittsburgh is generating a base of venture-backed firms, there is not the momentum found in aspirational peers like Austin, Denver, and Durham, N.C. In these cities, former technology startups have grown into large-scale companies that serve as employment generators for the region and have a cadre of founders reinvesting in tomorrow's growth firms. And while the universities are ramping up entrepreneurial activity—a greatly needed and welcome step—it's an open question whether the city is positioned to absorb and help these startups grow or whether these firms will seek customers, capital, and connections on the coasts.

There are a number of factors that help explain the lackluster growth of Pittsburgh startups. First, connections between academic institutions and the entrepreneurial ecosystem are not at the level they are among national leaders. While the metro area produces 230 percent of the national average in university research, its universities created only 25 percent more startups (as a share or research expenditure) than the average, and their patent and licensing income is lower than average.[25]

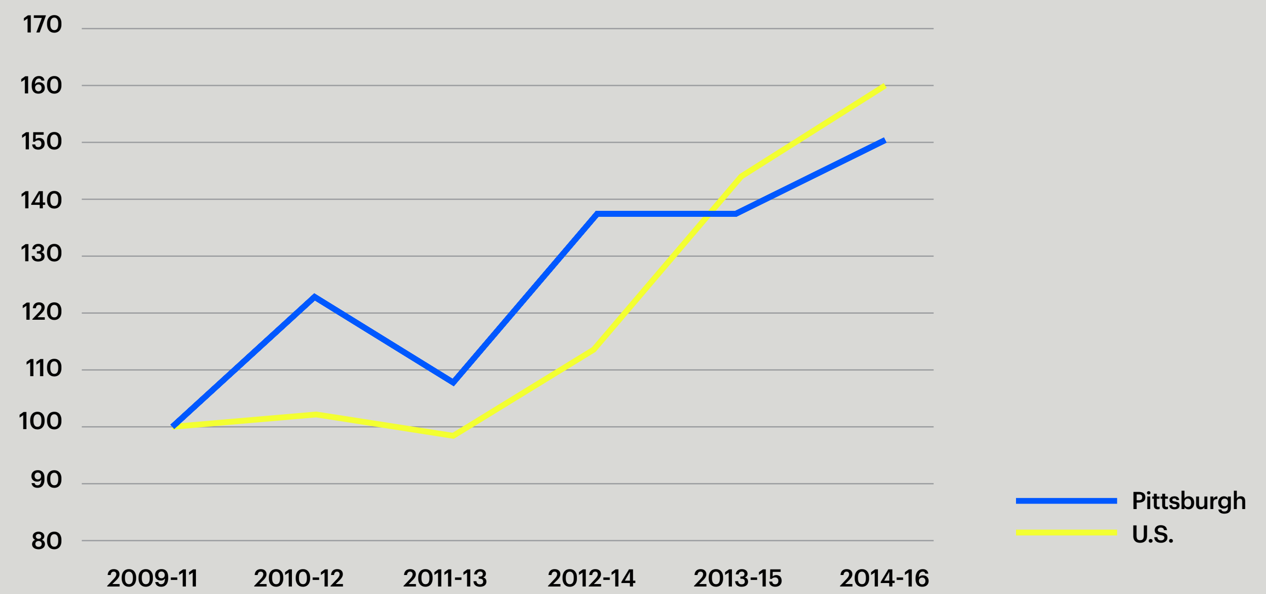
The University of Pittsburgh, which has made significant improvements in technology transfer and entrepreneurship in the last five years, still ranks below its peers for startups. Among similarly sized universities with a medical school, between 2009 and 2014 Pitt produced only two-thirds the average number of startups but 25 percent more licensing dollars.[26]

Moreover, pre-seed and other startup support activities are insufficient to meet the needs of the city's deep bench of research entrepreneurs, and the gap is only growing as Pitt and CMU increase their translational research capacity. Current SBIR/STTR assistance programs are not meeting demand, and funding declines from the Pennsylvania Department of Community Development and other state and federal sources have made the problem worse.

The connections between entrepreneurs and large firms is also weak. While the Pittsburgh Technology Council, Innovation Works, and other organizations seek to connect entrepreneurs with large companies, interviews suggest that fruitful "first customer" efforts (where young companies find their first sale from a regional large firm) are rare and few forums exist for entrepreneurs to get on the radar of larger companies. Intermediaries are disconnected from one another. In many interviews, organizations said either they were unaware about what others in the ecosystem were pursuing or even competitive with one another.

A second factor explaining the lackluster growth of startups in Pittsburgh is below-average growth in venture capital funding. While venture capital rebounded strongly in 2016 and reached the second-highest annual amount in five years,[27] for the 2014 to 2016 period (which smooths out year-to-year

Figure 5: Venture capital funding growth, Pittsburgh and U.S., 2009-2016 (2009=100)



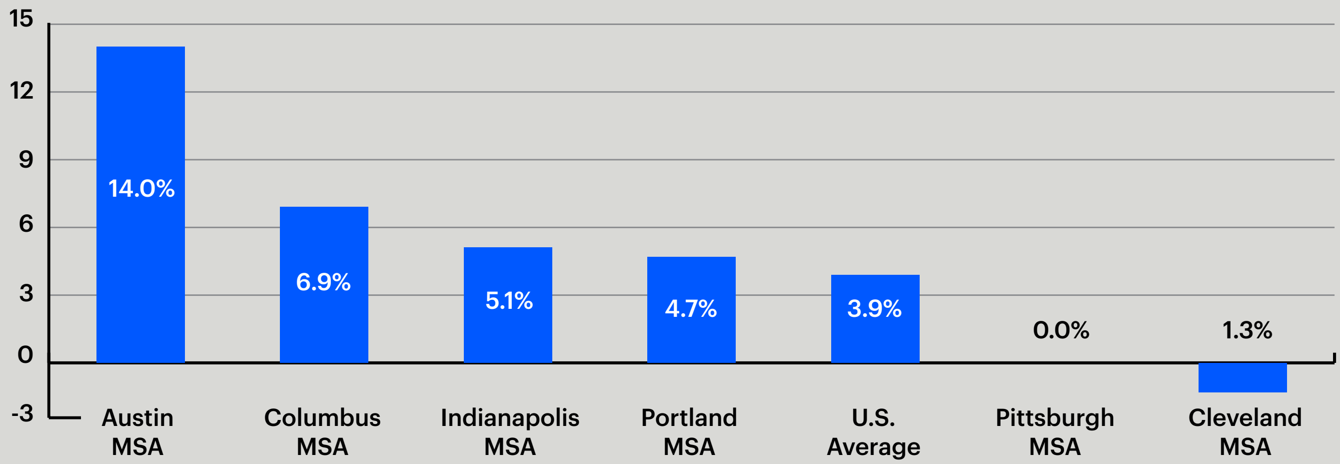
Source: Thomson Reuters Thomson ONE database, authors' calculations.

fluctuations) Pittsburgh is 30 percent lower in venture capital funding than the national average on a per capita basis. Comparing the three-year period 2014 to 2016 to 2009 to 2011, Pittsburgh's venture capital funding grew 51 percent, compared to 60 percent nationwide.

Funding constraints are even more pronounced for research-based startups. Entrepreneurs who seek to translate research findings in life sciences, robotics, computer science, and other fields into new companies traditionally rely on extensions of federal R&D funding and state programs. Unfortunately, these programs have been significantly reduced at the state level, and observers believe the federal government may begin an unprecedented process of rolling back funding for applied and commercial research. Given Pittsburgh's research-based strengths, reductions in programs like SBIR would have reverberating effects on local entrepreneurs.

Finally, Pittsburgh is not yet globally recognized as a premier destination for entrepreneurial talent. Despite national R&D strengths in next-generation technology areas with rapidly expanding global markets, the city doesn't have an international presence, particularly around entrepreneurs. This hamstrings the city's ability to link its technical capabilities to entrepreneurial success.

Figure 6: Change in total population, Pittsburgh and comparison regions, 2009-2014



Source: U.S. Census Bureau, American Community Survey, authors' calculations.

Demographic and skills headwinds threaten Pittsburgh's ability to create the broad workforce needed to compete, both within the innovation district and more broadly

Pittsburgh faces significant demographic and competitive pressures to its innovation workforce that if left unaddressed will stymie the city's growth. A clear conclusion of these pressures is that the innovation workforce must be far more inclusive than its current level in order to meet demand. Unfortunately, specifically within the innovation district, the expansion of a technology-based economy has not yet coincided with broad-based workforce opportunities for middle-skilled workers.

Pittsburgh is in a perilous time of demographic transition. Between 2009 and 2014 its population remained stagnant, while peers like Columbus, Ohio; Indianapolis; and Portland, Ore. grew 5 to 7 percent and Austin, Texas grew 14 percent (see Figure 6). The only peer city with slower post-recession growth than Pittsburgh was Cleveland. At the same time, the average worker in Pittsburgh is older than the national average, and a quarter of a million people are expected to retire over the next decade.[28] At the other end of the age spectrum, the K-12 pipeline alone is not large enough to meet the projected growth in workforce demand, and a deficit of 80,000 workers is expected by 2025.[29]

Pittsburgh's demographic slide is particularly pronounced among mid-career workers. Over the last half decade the region has lost 69,975 people age 35 to 54, more than any other peer city. By comparison, in that same period Austin gained 62,632 workers in this cohort. In interviews, chief executive officers (CEOs) said that retaining and attracting these workers is their most significant challenge. As one CEO put it, "in order to get in front of retirees we need a pipeline of middle-level (3 to 15 years) employees, but these folks are getting harder and harder to find."

The tightening labor market is amplified in the innovation economy. According to the Allegheny Conference, IT job openings in the Pittsburgh region will grow by 11 percent over the next decade, 2.6 times faster than the rest of the economy, yet the current and projected stock of workers is insufficient to meet demand.[30] While many of these positions require a bachelor's degree or higher, many do not. As IT capacity increasingly becomes a staple of every industry, firms will need IT workers across the educational spectrum. As one CEO noted, "75 percent of the IT jobs in the company don't require a four-year degree."

In sum, at projected population levels, current labor force participation rates, and workforce skill levels, Pittsburgh will not be able to meet the demands of growing advanced industries.

But despite the clear and present danger faced by the tightening labor market, not enough is being done—in the innovation district or the broader region—to upskill workers to fill the gaps. Pittsburgh has 32,000 long-term unemployed residents, the majority of whom were traditionally employed in low-skilled, low-growth occupations. Fewer than 1 percent of Pittsburgh's IT workers are African American, compared to 7 percent nationally.

In many ways, workforce dynamics within the Oakland innovation district are a leading indicator of where the city as a whole is going. Anchor institutions employ tens of thousands of workers in growth sectors, specifically health care. Within the Pittsburgh health care sector 55 percent of occupations require less than a bachelor's degree, and yet the district is adjacent to neighborhoods with systemic poverty and underemployment, such as the Hill District, Uptown, and Hazelwood, and a short bus ride from other low-income neighborhoods like Homewood. Workforce programming is not being utilized in these neighborhoods at high enough rates. For example, the percent of unemployed residents seeking workforce services in these neighborhoods is only 40 percent of the city's average rate.[31]

The issue is not simply one of supply and demand or even addressing the skills gap. Indeed, numerous training programs in Pittsburgh go unfilled as workers struggle to make the transition from unemployment or underemployment, often in the low-wage service sector, to the innovation economy. Job seekers report difficulty understanding online recruitment systems and many simply don't see viable pathways to careers in health care, manufacturing, or other high-value areas of Pittsburgh's economy.

While initial efforts at anchor institutions like Pitt to train and hire local workers in high-demand fields are underway, the growing Oakland innovation district is neither meeting its own workforce demand nor currently serving as a leading testbed for inclusion and workforce opportunities for the broader region.

Section 5: A path forward: Governance and recommendations

Pittsburgh's economy is increasingly driven by innovation, yet existing initiatives and investment levels are not meeting the demands of this new economy. What follows is a road map for translating the region's substantial strengths into meaningful economic activity for all. The recommendations fall within four broad areas of activity: **innovation clusters, the Oakland innovation district, high-growth entrepreneurs,** and **workforce development.**[32] Within each area are a number of strategies the region can take. Some of the recommendations will require years to plan, finance, and execute, while others can be achieved almost immediately. In the end, it will be up to local leaders to decide which initiatives to pursue first, how they are financed, and who should lead.

Pittsburgh has a number of existing institutions and organizations that are well positioned to take on the majority of recommendations called for, but these players will need to be supported by public, private, and civic leaders.

To that end, Brookings recommends launching a new initiative—**the InnovatePGH partnership**—to adopt and advocate a new narrative of Pittsburgh's economic future and to issue a call to action. The partnership, comprising public, private, and civic leaders, would rally new and existing resources to support the recommendations in this report and others demanded by the innovation economy.

Because Pittsburgh's research universities—specifically the University of Pittsburgh and Carnegie Mellon—represent the region's greatest innovation assets, these institutions are the ideal leads for the new partnership. Other prominent local institutions would champion specific recommendations and activities. For example, Innovation Works would be an ideal partner to lead programs around entrepreneurship, while Partner4Work would be excellent institution to lead workforce development programs.

The recommendations called for here are substantial and will likely need to be sequenced over the next decade. However, the innovation district offers a unique platform and locale to begin taking targeted action. Because the district houses such a substantial share of the city's innovation assets and institutions, it provides a natural starting point. Nonetheless, the weaknesses identified are spread across the city and the region and will need to be addressed within that broader context. As has been the case in other cities, Pittsburgh should use its innovation district as an organizing principle, not a geography.

Recommendation: Build and support Pittsburgh's innovation clusters in advanced manufacturing, life sciences, and autonomous systems

To build an innovation economy, city leaders need to adopt a focused, technology cluster approach. While there are many candidates—financial technology, corporate services, energy—three are clear first priorities: advanced manufacturing, life sciences, and autonomous systems. These three areas represent both low-hanging fruit and the most obvious opportunities because of their implications for major employment centers: advanced manufacturing already employs a significant share of workers in the metropolitan area, life sciences is a missing complement to the booming health care sector, and automation technologies are a platform that could influence a half dozen sectors throughout the Pittsburgh economy.

While creating long-term growth within each respective cluster will demand specific and unique strategies, the overlap between these three clusters is significant. For example, autonomous systems are an important comparative advantage for Pittsburgh's life science and health care cluster. Similarly, regional strengths in crosscutting technologies like data analytics have important implications for the success of all three clusters. As city leaders begin to build each cluster, they should remain aware of the points of connection between them.

Industry Cluster One: Establish a Pittsburgh-supply chain initiative in next-generation manufacturing

Pittsburgh needs to ensure that manufacturing firms in the region, of all sizes, both are using technologies that are redefining the sector and are participating in growing supply chains around the production of new technologies. While the city has significant research strengths in a host of relevant technologies—including robotics, additive, new materials, and data analytics—these advancements are not yet a fixture of local supply chains. Doing so will require stronger connections between the region's supply chain and universities and other intermediaries. The most obvious opportunity to create these connections in the near-term is within the Advanced Robotics Manufacturing Innovation Hub. While ARM is a national consortium located in Pittsburgh, local firms should have unique access to its facilities.

Specifically, the initiative would:

Leverage the ARM testbed facility for a wider range of Pittsburgh-based manufacturing industries.

ARM currently focuses on advanced robotics within the aerospace, automotive, electronics, and textile sectors. For Pittsburgh's advanced manufacturing economy to benefit more fully from ARM, it will be important to expand the reach of the testbed facility called for in ARM to consider applications for a wider range of industries found in the Pittsburgh region. These include energy, new materials, and metals and metal processing. Further, Pittsburgh's growing capability in additive manufacturing can provide a boost to the region's manufacturing base and should be addressed as a complementary technology platform.

Enhance industrial collaboration/technology transfer. Pittsburgh-focused efforts should build upon the ARM framework agreements that facilitate the transfer of technologies to predominately large manufacturers and expand these practices to firms of all sizes and across other manufacturing technologies. To do so, there should be specific strategies targeted at SMEs to facilitate and streamline technology transfer through regional master agreements, data-sharing agreements, and the establishment of technical leads within companies and service organizations to implement and demonstrate new technologies and applications developed specifically for SMEs. These efforts would need to be promoted to SMEs through workshops, seminars, and peer networks on key topics related to advances in the use of robotics and other technologies.

Engage national efforts for Pittsburgh's advantage. Standards development is fundamental for the adoption of advanced robotics. The National Institute of Standards and Technology (NIST) has an active, ongoing effort in leading the development of these standards through its Systems Integration Division.[33] The Pittsburgh-focused ARM should have the staffing capacity to be an active participant for the region to engage with these ongoing national efforts in smart manufacturing standards development at NIST. In coordination with standards development, the region should work to develop national models for the safety of autonomous systems and manufacturing.

Industry Cluster Two: bring to market life sciences R&D

Pittsburgh needs a more holistic approach to its nascent life sciences industry cluster that offers a pro-active economic development effort around

The NY-BEST model

The New York Battery and Energy Storage Technology Consortium (NY-BEST), created in 2010 by the New York State Energy Research and Development Authority (NYSERDA), has more than 150 members across a diverse community of manufacturers, academic institutions, utilities, technology and materials developers, engineering firms, systems integrators, and end users. Its Test and Commercialization Center offers testing for small single cell batteries to larger megawatt battery systems, product development, performance validation, certification testing, environmental testing, battery lifetime testing, mobile in-field testing, and onsite product commissioning. NY-BEST draws on the expertise of DNV GL, a global company with extensive energy advisory, testing, inspection, and certification expertise to serve its 150 members. The $23 million cost of the facility is supported by a public-private partnership, with $5.3 million coming from NYSERDA, $1 million from Empire State Development, and up to $16 million from DNV GL. In addition, NY-BEST has partnered with the Rochester Institute of Technology to offer its members the Battery Prototyping Center, involving laboratory facilities for cell assembly and moisture sensitive experiments. The center is another public-private partnership, with funding support from NYSERDA, Empire State, and SoLith, an engineering company for lithium-ion battery production automation.

growth, attraction, and retention of startups and existing companies. Industry-focused research should also be strategically linked to existing regional economic and technological strengths. Such an effort should complement ongoing applied research and help the existing and emerging base of life sciences companies to address critical business issues such as workforce, facilities, and partnering opportunities.

Pittsburgh, like many regions with leading academic medical centers, does not have a platform of leading life sciences companies to collaborate with the private sector and help to sustain industry growth. This was true at one time for Boston, San Francisco, New York City, and suburban Maryland, yet each of these regions are now successful in creating the high-value business environments needed for life sciences industry cluster development. This is a missing ingredient for Pittsburgh.

Advancing the development of a life sciences industry cluster in Pittsburgh will require a balanced approach between serving local existing and emerging life sciences companies and potential industry partners from outside the region. To accomplish this, city stakeholders should:

- **Form a comprehensive life sciences economic development organization.** The organization would serve as a champion to focus on retention, attraction, and the home-grown business development needed to support overall life sciences industry cluster development. Successful development will require establishment of a mechanism for bringing together the full life sciences industry community to address common problems and create stronger academic-to-industry and business-to-business relationships.

- **Build a center for translational research.** Across Pittsburgh there are significant shared-use facilities and basic and clinical research expertise that could benefit industry partners. The dedicated life sciences industry cluster entity working together with Pitt and UPMC should consider offering a one-stop resource for accessing such resources.

- **Establish a corporate innovation center matching fund.** Pittsburgh is seeking to catch up to the first wave of life sciences corporate innovation centers being formed across the United States. But even with a strong value proposition for corporate engagement, additional incentives are required. The use of these matching corporate innovation center funds might be targeted for capacity building activities, such as the recruitment of scholars to work with industry and academia to advance commercialization of innovative biomedical discoveries in select fields.

- **Create a signature industry partnership location in Oakland.** As Pittsburgh pursues industry-university collaborations as a strategic driver for life sciences development, it also must address the need for a landing site where major life sciences corporation R&D teams can have easy access to the extensive life sciences laboratory and clinical resources found in Pittsburgh as well as access to emerging life sciences companies. The center for much of this biomedical R&D activity is found within the proposed Oakland innovation district, but there is not a specific multi-tenant facility with appropriate amenities to cater to these industry collaboration partners.

Industry Cluster Three: coordinate and connect existing industries to autonomous systems

With the city's global strengths in machine learning, robotics, and artificial intelligence, as well as the presence of a growing cluster of firms such as Argo and Uber, few cities have the academic and research feedstock in autonomous systems as Pittsburgh does. The city clearly has a first mover's advantage, but, as with all transformative technologies, its position is not fixed or guaranteed. Other regions like the Bay Area, Detroit, and Boston have strong engineering and computer science universities, greater firm density, and the ability to amass private capital once the technology matures.

Pittsburgh must leverage its current national attention into a long-term competitive position. Unlike other sectors, autonomous systems hold the potential to be platform technologies for a host of other industries, and therefore cannot be approached like byway of traditional cluster strategies.

Therefore, Pittsburgh needs to start a coordinated effort between universities, automation and software startups, corporate research centers, and large, incumbent firms. The goal of the effort would be to identify industry-specific applications of automation technology and deployment strategies in large employment sectors.

To translate the research-based automation capacity of Pittsburgh into a full-blown economic cluster, city leaders should:

- **Create an executive-level taskforce to identify bridging opportunities between university research in autonomous systems and large economic sectors like finance, health care, and corporate services. Automobiles will continue to be the most visible application of autonomous** technology but Pittsburgh should leverage its strength to diversify its economy. To that end, in the next five years the region needs explicit strategies to growing value through autonomous systems within existing sectors.

- **Link autonomy with other cluster strategies.** Many elements of Pittsburgh's autonomous ecosystem clearly fit within other the other sector strategies. For example, recommendations around leveraging the ARM testbed facility regionally and building out applied research funding clearly have strong connections to autonomous systems development.

- **Establish a firm attraction and marketing strategy around autonomy.** Pittsburgh currently enjoys a favorable international reputation in autonomy thanks to Uber's self-driving car service and the Ford investment in Argo AI. The city should quickly develop a branding strategy to leverage its newfound national attention into global relevance, as there is an urgent need to connect Pittsburgh's capability in autonomous systems to the robust job growth potential in that sector.

To be successful, the three cluster strategies should develop in parallel tracks, though some actions will naturally be sequenced and require significant coordination with the others. While distinct, many of the activities could also rely on a shared office infrastructure, including economic development activities, marketing, and support staff.

Recommendation: Define, grow, and connect the Oakland innovation district

To reach its full economic potential for the city and region, the Oakland innovation district needs to be marketed, defined, and coordinated. In particular, a comprehensive, district-wide strategy is needed to leverage the ongoing investments at CMU, Pitt, and UPMC.

There is particular need for more multi-tenant shared space for incubation and accelerator activities, corporate innovation centers, and collaborative shared-use facilities for industry-university research activities in close proximity to Oakland's anchor institutions.

At the same time, strategies are needed to create a seamless integration of Oakland with the employment centers nearby, especially toward downtown. Given the topography of Pittsburgh, creating connectivity is a challenge, and so focusing on specific street corridors may be a means to improve the flow of traffic and density for connecting Oakland with downtown and other areas in the city.

Moving the Oakland innovation district forward will require at least four interrelated activities:

- **Establish a business development organization for the district** or task an existing institution that can pursue marketing of the innovation district to aggregate demand among potential tenants, interface with developers for multi-tenant space development, address zoning and master planning needs, determine services needed to meet tenant needs, and facilitate connections to the anchor institutions. One of the most important initial activities will be developing a branding strategy for the Oakland innovation district that can encompass its focus as a hub for research and innovation in Pittsburgh and its connections to other business areas.

- **Map the real estate assets that various public-sector entities control in greater Oakland and beyond,** together with university-owned real estate, to assess the value of public land. Vast holdings of the public sector are often overlooked, and their development potential goes unrealized. In addition to city and county real estate assets, those of public authorities, state entities, and federal agencies should be considered.

- **Develop a detailed district master plan** that leverages public-sector and university-owned real estate. A quality master plan for designing an innovation-led environment needs to consider how to create a broader environment able to activate engagement, offer mixed-use activities that can sustain vibrancy in the day and night, and establish an interconnected environment rather than a collection of isolated buildings.

- **Connect the district to the growing innovation clusters in other parts of the city,** including the Strip District/Lawrenceville, the North Side, Bakery Square, the Almono site, and others. Because of Pittsburgh's unique topography and organic growth, Oakland will serve as a hub among other innovation nodes, and city leaders should focus on building a network of interconnected spaces and programming that bridge the gaps between these areas. They should also focus on transportation solutions to do the same including the proposed Bus Rapid Transit system.

Recommendation: Improve the pipeline of high-growth entrepreneurs

Suggesting that the city focus on high-growth entrepreneurs for economic development may seem tautological. But though all startups aim to grow, some young firms are better positioned than others. Leaders in the city should create and build up existing programs that support firms aligned with existing strengths in industry and technology.

The first step, given the research strengths of Pittsburgh and increasing efforts among universities to improve faculty and student entrepreneurship, is ensuring that, when startups leave their research grants and other federal pre-seed funding programs, the city has the capacity to absorb these firms and support the next stage of their growth. SBIR continues to be a successful federal support system for technology firms and aligns with Pittsburgh's natural strengths, and so Pittsburgh needs to expand the number of researchers, tinkerers, and inventors applying for and receiving SBIR awards. Second, the city needs to build capacity for startups within the life sciences, health IT, and other clinical care solutions. These young firms have substantial upfront costs and require access to specialized resources, like wet lab space, and often have high-risk, long growth trajectories due to the need for clinical trials and/or FDA approval. Finally, given the number of large firms in Pittsburgh, a clear pathway to growth is through providing goods and services to these companies. However, connecting young firms with the needs of large companies is extremely difficult, and efforts to improve these connections in Pittsburgh have failed in the past.

To better align specific entrepreneurs with Pittsburgh's institutional, technological, and industrial strengths, several initiatives will need to be undertaken:

- **Establish a phase zero SBIR grant program** that builds on the state's IPart program, operated by Innovation Works that provides pre-proposal assistance, grant preparation support, and funding support for education, outreach, and travel.

- **Create a research entrepreneurs commercialization program** that provides recipients of federal R&D funding access to greater commercialization activities that are not included in existing research grants. These activities cover the gamut of important commercial activities, including intellectual property development and prosecution, marketing and market development, and the recruitment of a proven management team to help lead the growth of the company—all critical to commercialization.

- **Launch a global accelerator to grow and attract emerging companies in specific life sciences fields.** Pittsburgh's life sciences organizations need to create a comprehensive accelerator for young life sciences firms that brings together the region's academic, clinical, and industry strengths. Such an accelerator could be modeled after AlphaLab Gear, for example, but specifically tailored for the needs of health care startups (and likely including wet lab space).

- **Create a first customer program** in conjunction with a number of the city's largest firms and an entrepreneur intermediary. The program would aggregate and articulate grand challenges faced by regional firms that could be targeted by researchers and serve as a consistent, active conduit between entrepreneurs and companies.

Recommendation: Create a talent alliance coalition within the Oakland innovation district

Pittsburgh should create within the Oakland innovation district a talent alliance coalition of employers, existing workforce development organizations, and educational institutions. The coalition would identify critical occupational gaps within anchor employers in the district and develop and administer occupation-specific training for underskilled workers in the neighborhoods adjacent to the district and the broader region. While a number of workforce programs already exist, the purpose would be to aggregate employment demand in hard-to-fill occupations in health care, research, and education.

The alliance would then work with existing regional programs to develop training models within a suite of growing, innovation clusters such as advanced manufacturing and energy, information technology, and health care. The overarching goal of the group would be to identify workforce gaps in these sectors and develop clear strategies that require explicit commitments from both the private sector (in terms of resources and hiring commitments) and workforce programs (in terms of tailoring programs to meet the near-term needs of employers). The group should market the district to students and skilled workers outside the region; create a meeting place for large and SME employers, workforce and training providers, and educational institutions; and coordinate the many activities taking place within the district by individual organizations.

Workforce training will be essential to the advanced manufacturing cluster, for example. Workforce development robotics at the ARM facilities is essential, and the alliance could serve as a point of collaboration between regional training and educational providers. Activities would include skill upgrading for the existing workforce and new course and degree programs at the community college, four-year university, and graduate levels.

For technician training, the expansion of the ARM testbed should accommodate the need to create a hands-on experience working with specific automation and robotic equipment as well as experience with an advanced automation line that networks the various devices into one coordinated manufacturing line.

Of course, training programs address only the supply side of the workforce shortage, not the demand. Often job seekers have difficulty navigating the system or even believing jobs in the innovation economy are within their reach. Therefore, the talent alliance should work with organizations like Partner4Work to identify the soft constraints facing workers transiting from unemployment or underemployment, particularly in low-wage services, to the advanced economy.

Section 6: Pittsburgh 2030: An innovation job generator, or a 'could have been'?

Looking back in 2030, what will Pittsburghers think about the actions taken this decade by public, private, and civic leaders? Will they credit the strategies designed and resources rallied as sufficient or deem them inadequate?

The answer will depend on the state of Pittsburgh's economy in the decades to come. There are at least two plausible scenarios.

In the first, the city's economy is aptly described as two Pittsburghs. One continues to be driven by university research, small high-tech firms, and a handful of corporate research centers. The city will still be at the technological frontiers. CMU will continue to graduate the top 100 computer scientists in the country each year, and a few of these graduates will take jobs in local tech companies while the majority head to the coasts.

The other economy, which includes the majority of workers and families, consists of local services and traditional low- and mid-level manufacturing jobs that, as in much of the Rust Belt, continue to be automated or outsourced at a consistent rate each year. Average income and unemployment hover at or below the national level, with significant variance depending upon the neighborhood, and the city's population shrinks.

In a more dynamic scenario, Pittsburgh's economy flourishes. The lines between academic research and industry innovation are indistinguishable, as major employers in health care, finance, corporate services, and manufacturing collaborate, adopt, and deploy technology to stay ahead of global competitors. As such, high-value exports of both goods and services expand, creating a reliable tax base and a pool of high-wage jobs. Well-resourced and coordinated education and workforce programs identify and attack unemployment in high-poverty neighborhoods. Securing a lifelong job in a factory by a worker with a high school education is as unrealistic in the future as it is today, but, unlike today, the high school graduate and everyone else has options. In this scenario the innovation economy is Pittsburgh's economy, and all benefit.

Both scenarios are realistic. The outcome will be determined by the investments made today.

Appendix A: Performance of Pittsburgh's leading advanced industries

This appendix sets out the approach and findings from a detailed examination of leading advanced industry drivers found in the Pittsburgh region. The focus on leading industries is not about picking individual corporate winners and losers. Rather, it is about identifying those crucially important industries that have significant and quantifiable growth momentum in the regional economy and that can offer the promise of good quality jobs and economic prosperity.

Approach to this study

Research shows the significance of innovation for economic growth and rising living standards. Studies have found that 90 percent of the variation in the growth of worker incomes across nations is related to how effectively human and physical capital is used, as measured by productivity gains (a surrogate measure of the impact of innovation).[34] The Congressional Budget Office estimates that nearly half of U.S. projected growth in the 2014–2024 period will be driven by rising productivity from innovation.[35] Economists at the Federal Reserve Bank of Cleveland found that increased innovation, as evidenced by growing levels of patent activity, is one of the most significant factors in determining a state's level of per capita income, outstripping other factors behind growing per capita income such as tax burdens, public infrastructure, and the size of private financial markets.[36]

Broad industry categories used in report

- *Advanced industries*—innovation-driven, skilled, and export-oriented industries as identified by the Brookings Institution
- *Advanced business & health services*—key complements to advanced industries that may also drive growing economic activity

In line with the new imperative for regions to focus on innovation-based economic growth, the Brookings Institution has identified a set of "advanced industries," defined as industries that invest significantly in science, technology, engineering, and math (STEM) workers.[37] These industries anchor American economic well-being by ".... encompass[ing] the nation's highest-value economic activity. As such, these industries are the country's best shot at innovative, inclusive, and sustainable growth."[38] Advanced Industries include a wide range of manufacturing industries as well as engineering, software/computer services, and commercial research and testing services actively involved in exports and that bring new income into local economies.

Complementing these advanced industries at a regional level are advanced business and health services, which in Pittsburgh are a large part of the export economy. They serve customers within and outside the region, require a skilled workforce, advance and/or deploy leading technologies, and provide the business and technical services needed for the success of advanced industries.

A full list of advanced industries, including advanced business and health services, appears at the end of this appendix in Table A-9.

Identifying leading industry clusters in Pittsburgh

While this paper discusses three major clusters—advanced manufacturing, life sciences, and autonomous systems—there are many smaller industry clusters that come together in around these areas. This appendix identifies eleven more narrow clusters that were used to analyze Pittsburgh's innovation economy and to develop the recommendations. Together, these eleven are considered Pittsburgh's "advanced clusters" or advanced industries.

An industry cluster is a group of firms, related economic actors, and institutions that are located near one another

"Clusters are a striking feature of virtually every national, regional, state, and even metropolitan economy, especially in more economically advanced nations....Clusters are not unique; however, they are highly typical—and herein lies a paradox: the enduring competitive advantages in a global economy lie increasingly in local things—knowledge, relationships, motivation—that distant rivals cannot match."

Michael Porter, "Clusters and the New Economics of Competition," *Harvard Business Review*, November-December 1998.

and that draw productive advantage from their mutual proximity and connections.[39] The idea that state and regional development is driven by industry clusters of geographically localized concentrations of firms in related sectors that do business with each other and have common needs for trained workers, infrastructure, and technology goes back in the economic literature to the writings of Alfred Marshall in the late 19th and early 20th centuries.[40] But industry cluster development as a best practice for economic development has taken hold only in the past two decades, and its application has been primarily focused on enabling states and regions to compete in high-growth, innovation-led development.

There is no standard set of industry clusters for advanced industries that fits each region. The composition of clusters in Philadelphia would make little sense in Pittsburgh, for example. Instead, identifying regional advanced industry clusters requires analyzing the specific local advanced industries that are focused on economic base activities and determining where there are logical connections and interrelationships in the regional economy.

Identifying the appropriate clusters within Pittsburgh's economy involved a three-step process:

1. Advanced industries and advanced business and health industries in Pittsburgh were analyzed at the most detailed industry levels.[41] to understand what industries stand as economic drivers based on size, relative concentration/specialization, and recent trends, particularly against national performance.

2. Clusters based on the inter-industry relationships of prominent advanced industries were constructed. Input/output models showing the purchases of goods or services between industries enabled the identification of industries that do business together. Data from IMPLAN, which relies on a widely used model that customizes likely supplier chain relationships based on the economic structure found in each state, informed the cluster analysis.

3. The data were complemented by an examination of the presence of large firms and their activities. Information from corporate databases and company websites was accessed to understand companies' products, services, and applied technologies and where each fits relative to other industries in the state.

The analysis identified 11 distinct industry clusters driving Pittsburgh's economy. Table A-1 summarizes the major industry components of these clusters and provides examples of leading firms found in Pittsburgh.

Table A-1: Eleven distinct industry clusters driving Pittsburgh's economy

Industry cluster	Types of industry activities	2015 size in Pittsburgh region	Examples of leading companies
Automation and industrial machinery	Relay and industrial control manufacturing Industrial process instruments Measuring and controlling devices	6,909 jobs 118 establishments	Westinghouse; Sensus Metering Systems; Emerson; Industrial Scientific Corp.; Eaton
Chemicals, polymers, and other non-metal materials ("chemicals / polymers")	Petroleum/coal-based chemical products Plastic materials and resin manufacturing Inorganic chemical manufacturing	13,177 jobs 266 establishments	Bayer; Axiall; Eastman Chemical; Carbide/ Graphite Group; Nova Chemicals
Computing, networking, information services, and internet applications ("computing")	Custom computer programming Computer systems design Software publishing Data processing, hosting, and related services	17,474 jobs 1,138 establishments	Capgemini (iGate); HCL Global Systems; Nityo Infotech Corp; IBM; Google
Corporate services	Managing offices (i.e., headquarters) Administrative consulting services Human resource consulting Marketing consulting	47,596 jobs 1,733 establishments	Deloitte; Management Science Associates; AON Hewitt; Development Dimensions International
Electronics manufacturing	Switchgear Telephone equipment Wiring devices	5,928 jobs 94 establishments	Eaton; Mitsubishi Electric Power Products; Aerotech; Compunetix; Windurance
Energy	Natural gas extraction Nuclear power Electric power generation Electric power distribution	18,732 jobs 519 establishments	Consol; West Penn Power; Pennsylvania Transfer Technology; Pennzoil-Quaker; GE Power Conversion
Engineering, commercial research, and technical services ("engineering / technical services")	Engineering services Testing laboratories Environmental consulting Physical and biological research	29,766 jobs 1,680 establishments	Bechtel; Thermo Fisher Scientific; Disney Research

Industry cluster	Types of industry activities	2015 size in Pittsburgh region	Examples of leading companies
Finance and insurance services	Commercial banking Health insurance provider Property and casualty insurer Portfolio management	54,691 jobs 3,481 establishments	PNC; Servicelink; Highmark; Chicago Title Insurance; HM Insurance Group
Health services	General medical and surgical hospitals Diagnostic imaging centers Blood and organ banks	93,601 jobs 1,446 establishments	UPMC; Allegheny General
Medical technology products	Electromedical devices Surgical and medical instruments Medical laboratories	8,809 jobs 321 establishments	Phillips Respironics; Zoll Services; Thermo Fischer Scientific; Berkley Medical
Metals & metal processing	Iron and steel mills Ferroalloy products Copper foundries Railroad rolling stock mfg.	29,276 jobs 795 establishments	US Steel; Gupta Permold; Duraloy Technologies

Performance of Pittsburgh's innovation-leading drivers

Pittsburgh's 11 advanced industry clusters represent key drivers of economic activity and employment in the region. With 326,000 jobs in 2015, these 11 clusters represent one-third of private-sector employment in the region. From 2009, the beginning of the economic recovery, through 2015, the job growth of these clusters nearly doubled that of the overall private sector in Pittsburgh—8.4 percent versus 4.4 percent. Six out of 10 new jobs added to the Pittsburgh economy have been generated from these 11 advanced industry clusters.

While the generation of jobs is an important measure of success, many other measures of the economic performance of the advanced industry clusters need to be considered. A comprehensive set of performance measures for each of the advanced industry clusters include:

- Relative concentration in the local economy compared to the nation;
- Job generation;
- Relative growth compared to the nation;
- Relative productivity levels compared to the nation;
- Average wages;
- Economic multiplier impacts on the Pittsburgh economy.

Defining the key measures of advanced industry performance for Pittsburgh

Relative concentration—a measure of how specialized an advanced industry is in Pittsburgh relative to the nation, or a gauge of the "competitive advantage" for the advanced cluster in Pittsburgh. The specific measurement of relative concentration is known as a location quotient, the share of Pittsburgh's employment found in a particular advanced cluster divided by the share of total industry employment in that advanced cluster for the nation. A location quotient that is substantially above the national average is considered "specialized."

Job generation—a straightforward measure of whether an advanced cluster has been gaining or losing jobs in Pittsburgh.

Relative growth—a measure of whether a local advanced cluster is gaining or losing competitive share compared to the nation. It is the difference between the percentage change in employment in an advanced cluster in Pittsburgh minus the percentage change in employment in that same advanced cluster for the nation.

Productivity —a measure of the economic output generated by each job. Comparing the level of productivity of Pittsburgh's advanced cluster to the national level informs whether the Pittsburgh advanced cluster is better able to make use of advances to produce goods and services and is able to produce more complex, higher-value products.

Average wages—a reflection of the overall quality of jobs found within an advanced cluster. It is a measure that relates the contribution of the cluster to Pittsburgh's per capita income and ultimately to the economic well-being of the state. By comparing average wage levels across advanced clusters, it is possible to learn which industries offer high-quality jobs.

Economic multiplier—a measure of the broader economic impact of each cluster's economic activity on the local economy. Of importance for economic development is how inter-connected an advanced cluster is to the regional economy.

Relative concentration of the advanced clusters

In regional economic analysis, a common metric of specialization is a *location quotient*, the share of a local area's employment found in a particular cluster divided by the national share of industry employment in that cluster. A location quotient greater than 1.0 indicates a higher relative concentration, whereas a location quotient of less than 1.0 signifies a relative underrepresentation. A location quotient approaching 1.20 denotes employment concentration significantly above the national average and indicates specialization.

Nine of Pittsburgh's 11 advanced industry clusters stand as specialized industries (see Table A-2), an impressive level of specialization given the city's industrial diversity spanning manufacturing, technical services, health services, and finance and insurance. Together, the 11 advanced industry clusters are 33 percent more concentrated in Pittsburgh than in the nation.

Given Pittsburgh's rich manufacturing legacy, it is not surprising that all the traditional advanced manufacturing clusters in the region are highly specialized. The most specialized include automation and industrial machinery and metals & metal processing, with each having more than two times the national employment concentration. The advanced industry cluster of engineering/technical services is 46 percent more concentrated than the nation, suggesting that Pittsburgh's manufacturing base is competing on the basis of innovation. This emphasis on technology services foreshadows the strength of advanced manufacturing in productivity levels, as discussed below.

Other large advanced business and health service industries also stand out as industry specializations and point to the diversification of the region's economy. Corporate services, largely reflecting the presence of headquarter operations, is 45 percent more concentrated in Pittsburgh than in the nation. Health services is not far behind at 33 percent more concentrated, which is remarkable since health care is traditionally viewed as a sheltered industry that nearly all regions require to serve local needs. In Pittsburgh, this high level of specialization points to a clinical excellence in health care that attracts patients from well beyond the region. The finance and insurance cluster is 15 percent more concentrated in Pittsburgh than in the nation, but with 55,000 employees it towers over more traditional manufacturing industries as an economic driver for the region.

The two advanced clusters in Pittsburgh that are lagging in national industry specialization are computing and

Table A-2: Relative concentration of Pittsburgh's 11 advanced clusters compared to U.S. overall

Advanced cluster	Degree of specialization (location quotient),2015
Automation and industrial machinery	2.61
Metals and metal processing	2.09
Chemicals/polymers	1.83
Engineering/technical services	1.46
Corporate services	1.45
Energy	1.42
Health services	1.33
Electronics manufacturing	1.26
Finance and insurance	1.15
Medical technology	0.97
Computing	0.73
Pittsburgh advanced clusters	**1.33**
Pittsburgh total private sector	**1.00**

Source: IMPLAN and QCEW.

medical technology, a pattern that raises concerns about the disconnect of industry and university strengths. The medical technology industry cluster is 3 percent lower in concentration than nationally and the computing industry cluster is 27 percent lower, surprising levels given the outstanding research strength of Carnegie Mellon University in computer science, where it typically ranks as the best in the nation, and the strength of the University of Pittsburgh and UPMC in academic medical research. This disconnect between industry and university specializations is of great concern and suggests areas for improvement to advance Pittsburgh's innovation economy and the economic success of the region.

Job generation by the advanced clusters

Job generation is one of the primary measures of whether an industry is growing or declining, and for the economy as a whole it is a key measure of economic growth. This assessment considers the 2009 to 2015 period, since those years show the change in jobs since the beginning of the current economic recovery through the most recent year of available data.

In job generation, nine of the 11 advanced clusters have grown, one has remained flat (metals and metal processing), and one has declined (electronics manufacturing). Overall, the 11 advanced clusters grew

Table A-3: Job generation from 2009-2015, percentage change for Pittsburgh's 11 advanced clusters

Advanced cluster	Percentage employment growth, 2009-2015
Computing	46.4%
Energy	32.7%
Corporate services	18.5%
Engineering/technical services	18.3%
Chemicals/polymers	10.4%
Automation and industrial machinery	6.3%
Finance and insurance	1.8%
Medical technology	1.1%
Health services	0.8%
Metals and metal processing	-0.4%
Electronics manufacturing	-4.0%
Pittsburgh advanced clusters	**8.4%**
Pittsburgh total private sector	**4.4%**

Source: IMPLAN QCEW.

by 8.4 percent, well outpacing the 4.4 percent growth of Pittsburgh's private-sector industries overall (see Table A-3).

Computing is the fastest-growing advanced cluster, with job growth of 46.4 percent from 2009 to 2015, albeit from a low base, suggesting that Pittsburgh may be turning a corner on this industry that has had a low industry specialization despite strong university research presence. The other lagging advanced cluster in industry specialization, medical technology, has not had the same success, but it is growing at a low 1.1 percent.

Despite the flat to declining growth in metals and electronics clusters, other advanced manufacturing clusters are making sizable gains, led by energy (32.7 percent), chemicals/polymers (10.4 percent), and automation and industry machinery (6.3 percent)

Among the services-oriented advanced industries, both corporate services and engineering/technical services are growing robustly, each advancing by more than 18 percent from 2009 to 2015. Health services, however, similar to medical technology, is advancing at a low rate, 0.8 percent.

Table A-4: Relative growth of employment in Pittsburgh's 11 advanced clusters, 2009–2015, compared to U.S. overall

Advanced cluster	Pittsburgh's relative employment growth compared to U.S., 2009 – 15 (percentage point difference)
Energy	16.8
Computing	16.1
Engineering/technical services	7.1
Chemicals/polymers	3.2
Electronics manufacturing	1.2
Automation and industrial machinery	-1.6
Finance and insurance	-2.0
Corporate services	-2.7
Medical technology	-4.9
Health services	-5.4
Metals and metal processing	-12.8
Pittsburgh advanced clusters	**-2.6**
Pittsburgh total private sector	**-6.0**

Source: IMPLAN QCEW.

Relative employment growth of the advanced clusters

In considering how an advanced industry cluster is performing, it is important to assess whether it is gaining or losing market share compared to that cluster at the national level. It may be that an advanced cluster is gaining jobs but still not keeping pace with national growth and so losing market share. Alternatively, an advanced cluster declining in jobs locally may be performing better than the nation and so gaining in competitive share, suggesting more resilience than the nation overall.

The relative employment growth of the advanced clusters considers the differences between the percentage change in employment for Pittsburgh minus the percentage in employment in that same cluster for the nation. The period 2009 to 2015 is used to view how the industry has recovered since the Great Recession.

All the advanced clusters found in Pittsburgh grew nationally from 2009 to 2015, except for electronics manufacturing, which declined (see Table A-4). This broad base of growth reflects the fact that the national recovery underway is widely shared among advanced industries.

Relative to the average national job growth from 2009 to 2015, Pittsburgh's advanced clusters have had a mixed performance, with just five of the 11 advanced clusters outpacing national employment trends. Most impressive, however, is that the energy and computing clusters each outpaced national growth by more than 16 percentage points. Engineering/technical services also grew much faster than the nation, at 7.1 percentage points higher, while chemicals/polymers and electronics manufacturing slightly outpaced the nation.

More generally, however, the 11 advanced clusters were slightly off the pace of the nation, growing 2.6 percentage points slower in Pittsburgh. This decline still outperformed the overall economy of Pittsburgh, which across all private-sector industries grew 6 percentage points less than the nation. The slower growth of both advanced clusters and private-sector industries in Pittsburgh points to the continued economic headwinds that the city is confronting.

Productivity of the advanced cluster

Advanced economic development is more than just promoting the growth of startup companies that are commercializing new technologies. Just as critical, if not as widely heralded, is the ability of industry to put technology to work. To assess Pittsburgh's competitive position in technology deployment, Brookings and TEConomy analyzed output per worker to compare Pittsburgh's overall economy and advanced clusters to national levels of productivity. Higher output per worker compared to the nation suggests more effective deployment of technologies in production as well as an ability to produce more complex, higher-value products. Value-added per employee is calculated from data on employment and output reported for industries in Pittsburgh and the United States by IMPLAN.

Pittsburgh has a mixed performance among its advanced clusters in productivity levels compared to the nation (see Table A-5). On the positive side, nearly all the manufacturing clusters in Pittsburgh stand higher than the nation, with the exception of electronics manufacturing. This strong showing suggests the continued competitiveness of the region in manufacturing.

Corporate services is the only advanced cluster outside of manufacturing that has a higher productivity level than the nation. Several other advanced clusters are not far off national productivity, including engineering/technical services, health services, and computing. Advanced clusters well below the national average are finance and insurance, medical technology, and electronics manufacturing.

Overall, the 11 advanced industry clusters have a slightly higher level of productivity than the nation, while all private-sector industries in Pittsburgh are slightly lower than the nation. The differences compared to the nation are small, which suggests that productivity is best viewed on an industry cluster-by-cluster basis.

Table A-5: Relative productivity of Pittsburgh's 11 advanced clusters, compared to U.S. overall

Advanced cluster	Pittsburgh's relative productivity compared to U.S., 2015
Corporate services	127%
Energy	119%
Metals and metal processing	119%
Chemicals/polymers	108%
Automation & industrial machinery	106%
Engineering/technical services	99%
Health services	93%
Computing	90%
Finance and insurance	82%
Electronics manufacturing	57%
Medical technology	57%
Pittsburgh advanced clusters	**103%**
Pittsburgh total private sector	**98%**

Source: IMPLAN.

Average wages in the advanced clusters

Economic development focuses not just on jobs but on the quality of jobs, and the average wages paid by each cluster are an important measure of the quality of the jobs created. As presented in Table A-6, the average wage across Pittsburgh's 11 advanced clusters is well above the overall average wage for the region. All of the advanced clusters, except for health services, have an average wage above the regional average. This performance demonstrates the importance of these advanced clusters for creating high-quality jobs that can raise overall standards of living and promote economic prosperity.

Compared to the national levels of average wages, though, the advanced clusters generally fall short. Across all advanced clusters, Pittsburgh stands at 92 percent of the national average wage, a level on par with the lower cost of living in Pittsburgh. However, overall average wages in Pittsburgh are at the national average. Two advanced clusters in Pittsburgh that stand out with higher wages than advanced clusters nationally are corporate services and metals & metal processing, each of which have much higher productivity than the nation. The other clusters with higher productivity in Pittsburgh than the nation are close to the U.S. average wages. The clusters well off the U.S. level of productivity generally have much lower wages compared to the United States overall.

Table A-6: Average wages for Pittsburgh's 11 advanced clusters, level and percentage of U.S. average wages, 2015

Advanced cluster	Pittsburgh	Percentages of U.S. average wages, 2015
Corporate services	$126,131	120%
Energy	$96,042	98%
Computing	$95,367	83%
Engineering/technical services	$86,227	94%
Finance and insurance	$79,745	81%
Medical technology	$71,319	69%
Automation and industrial machinery	$70,590	98%
Electronics manufacturing	$68,723	72%
Metals & metal processing	$60,906	110%
Chemicals/polymers	$59,416	98%
Health services	$46,739	93%
Pittsburgh advanced clusters	**$76,270**	**92%**
Pittsburgh total private sector	**$52,829**	**100%**

Source: IMPLAN.

Economic multiplier of the advanced clusters

It is important to consider the broad impact of each industry on the region's economy, and one way to do this is to analyze the economic impact from a $1 million increase in economic activity or output. This was accomplished using the IMPLAN input-output model for the Pittsburgh region, a tool that estimates inter-industry purchasing (indirect multiplier) and income effects from personal consumption of increased wages paid (induced multiplier) in the region.

Indirect multipliers estimate the local economic activity generated from the purchase of goods and services up and down the supply chain to support the production of the industry being analyzed. This is a measure of the local supply chain impact of the industry. The strength of indirect impacts is influenced by the strength and capacity of local suppliers to meet the input needs of a business. The larger and more diverse the local economy and the stronger the local supply chain, the higher the indirect impacts will be.

Additional economic impacts from an increase in economic activity occur through the wages paid to workers that are re-circulated through the regional economy as the wage earners make their own purchases. These are known as induced multipliers.

As shown in Table A-7, the highest total impact of a $1 million increase in economic output is generated by clusters representing largely services industries, including engineering/technical services, finance and insurance, corporate services, and health services. Part of this impact is due to the induced impact of wages paid, which is expected due to higher wages paid and the larger share that wages compose of output.

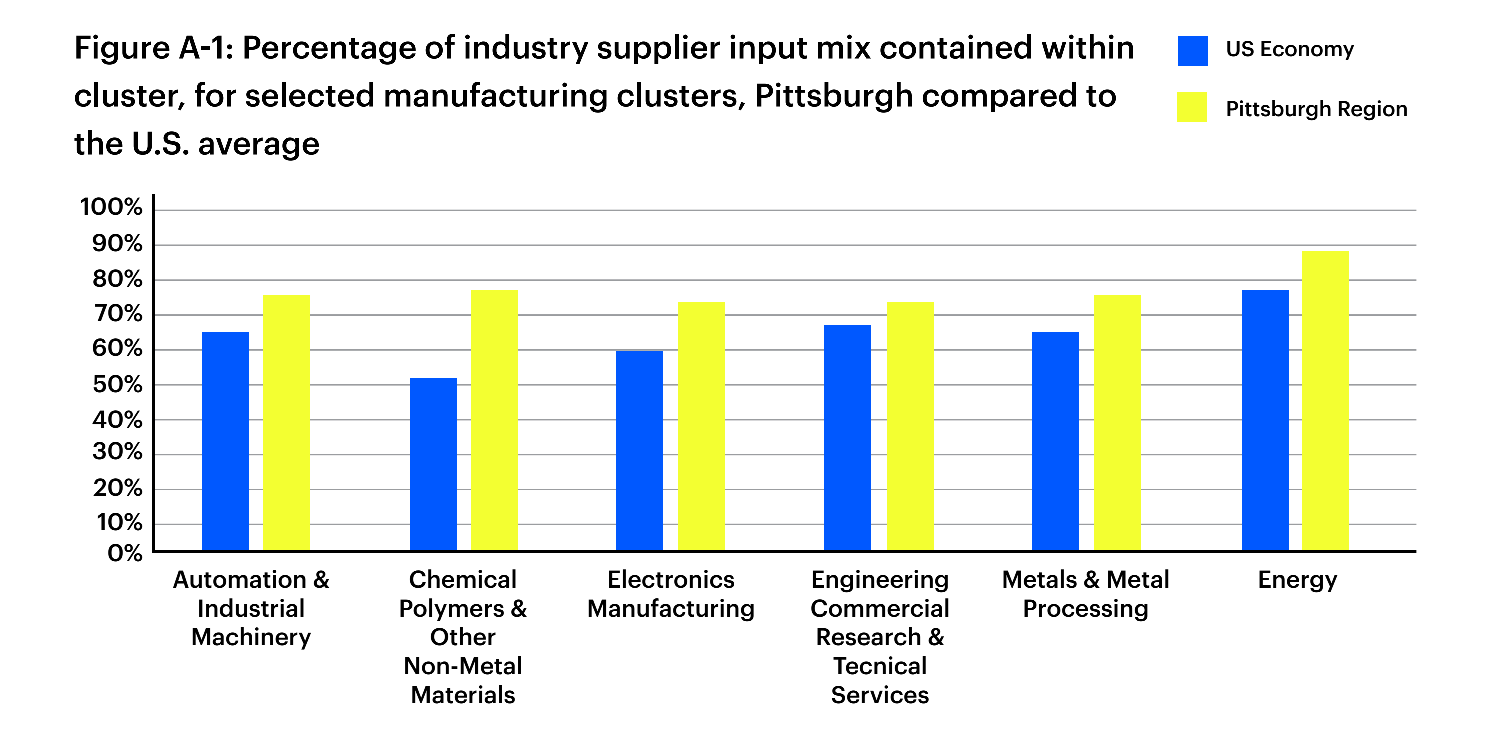
What is surprising is that for several of these service-oriented advanced clusters the indirect impact from inter-industry purchasing is higher than for advanced clusters in manufacturing. For instance, engineering/technical services and finance & insurance exceed the indirect impact for all manufacturing industries. While manufacturing usually has a stronger regional supply chain than services, this is not the case for Pittsburgh.

Further analysis suggests that the advanced manufacturing industries in Pittsburgh tend to have fewer supplier relationships and are more internally integrated. As shown in Figure A-1, Pittsburgh's manufacturing clusters have higher levels of internal capacity within each cluster that offsets the need for broader purchasing across supplier-based services and goods compared to the U.S. average. Thinner regional supplier networks limits the broader regional industry impacts of growth in these manufacturing industries, and suggests that as manufacturing has evolved in Pittsburgh the industry clusters have become more

Table A-7: Output multipliers for Pittsburgh's 11 advanced clusters, impact per $1 million increase in economic activity

Advanced cluster	Indirect impact ($ millions)	Induced impact ($ millions)	Total indirect and induced impact ($ millions)
Engineering, commercial research, and technical Services	$0.514	$0.599	$1.113
Financial and insurance	0.606	0.492	1.098
Corporate services	0.360	0.591	0.950
Health services	0.393	0.554	0.947
Computing, networking, information services and internet applications	0.421	0.443	0.864
Medical technology	0.440	0.372	0.811
Energy	0.409	0.334	0.743
Electronics manufacturing	0.383	0.294	0.677
Automation and industrial machinery	0.358	0.319	0.677
Metals and metal processing	0.407	0.263	0.670
Chemicals, polymers, and other non-metal materials	0.338	0.217	0.556

Source: IMPLAN.



Source: U.S. Census Bureau, American Community Survey, authors' calculations.

vertically integrated and draw on fewer suppliers.

Additional analysis also finds that Pittsburgh's manufacturers are drawing upon the services of the computing cluster at 75 percent of the level that manufacturers are nationally. This points to continued opportunities to deepen the supply chain and broaden economic impacts of manufacturing in the region.

Summary and conclusion on the performance of Pittsburgh's advanced clusters

The advanced industry clusters identified in Pittsburgh are important drivers of economic growth in the region. Since the economic recovery, these clusters have experienced nearly twice the overall job growth of the region—8.4 percent compared to 4.4 percent for all private-sector industries. The jobs added by the growth of advanced clusters are high-quality jobs, with average wages more than $22,000, or 44 percent, higher than the average for all private-sector jobs in Pittsburgh.

Despite the importance of these advanced clusters for the Pittsburgh economy, their performance relative to the nation is mixed. Job gains by the advanced industry clusters since the recession have been healthy, but the clusters are lagging behind the United States overall by 2.6 percentage points. In average wages, Pittsburgh receives only 92 percent of the U.S. average across the 11 advanced clusters.

One bright spot is that productivity, a critical measure of the economic competitiveness of the region's industries, is higher on average within the advanced clusters in Pittsburgh than it is nationwide. A closer examination, however, finds that only manufacturing industries stand above the nation, and other advanced clusters, including computing, medical technology, and finance and insurance are lagging.

Similarly, the advanced clusters in Pittsburgh employ 33 percent more workers than expected given the size of the overall economy, implying that these clusters represent clear areas of specialization. But two advanced clusters, computing and medical technology, that lag the U.S. level of employment concentration represent world-class research strengths engendered by Pittsburgh's universities, and the fact that they lag suggests a significant disconnect between regional industry growth and regional research strengths.

A summary of how each of the advanced clusters is faring across the six economic performance indicators is set out below. Nearly all the advanced clusters stand out in at least two of the indicators, with several high-to-strong performers and a couple of advanced clusters generally lagging in their performance.

- **High-performing clusters:** Engineering/technical services and energy clusters stand out in not having any weak performances across the six economic performance indicators.
- **Strong-performing clusters:** Corporate services and chemicals/polymers clusters have only one weak performance across the six indicators.
- **Moderate-performing clusters**: Five of the advanced clusters have strong performances in at least two of the indicators, including metals & metal processing, health services, finance & insurance, computing, and automation & industrial machinery.
- **Weak-performing clusters**: Medical technology and electronics manufacturing have weak performance in four of the six indicators.

Looking forward, the breadth and diversity of Pittsburgh's advanced clusters suggest that they can be strong drivers of regional growth in the years to come. Among the region's priorities for ensuring that this potential can be realized is, first, addressing the disconnects identified in the analysis, including between the region's research strengths and industry development in computing and medical technology, and, second, better integrating the region's manufacturing base with other industries in the region, including computing.

Table A-8: Summary of Pittsburgh's advanced industry clusters' position relative to the U.S.

Technology cluster	Relative concentration 2015	Job generation 2009-15	Relative growth 2009-15	Relative productivity 2014	Relative average wages 2015	Output
Automation & industrial machinery	▲	■	▼	▲	■	▼
Chemicals/ polymers	▲	▲	■	▲	■	▼
Computing	▼	▲	▲	■	▼	■
Corporate services	▲	▲	▼	▲	▲	▲
Electronics manufacturing	▲	▼	■	▼	▼	▼
Energy	▲	▲	▲	▲	■	■
Engineering/ technical services	▲	▲	▲	■	■	▲
Finance & insurance	▲	■	▼	▼	▼	▲
Health services	▲	■	▼	■	■	▲
Medical technology	■	▼	▼	▼	▼	■
Metals & metal orocessing	▲	▲	▼	▲	▲	▼
Strong performance: ▲	LQ > 1.2	> 10%	> 5%	> Nation	> Nation	>$900k
Moderate performance: ■	LQ .8 - 1.2	0% - 10%	0% - 5%	90% - 100% of Nation	90% -100% of Nation	$750k- $900k
Weak performance: ▼	LQ < .8	Negative	Negative	< 90% of Nation	< 90% of Nation	>$750k

Table A-9: List of advanced industries

NAICS code	NAICS title
Advanced Industries—Brookings Institution definition	
2111	Oil and gas extraction
2122	Metal ore mining
2211	Power generation and supply
3241	Petroleum and coal products manufacturing
3251	Basic chemical manufacturing
3252	Resin, rubber, and artificial fibers mfg.
3253	Agricultural chemical manufacturing
3254	Pharmaceutical and medicine manufacturing
3259	Other chemical product and preparation mfg.
3271	Clay product and refractory manufacturing
3279	Other nonmetallic mineral products
3311	Iron and steel mills and ferroalloy mfg.
3313	Alumina and aluminum production
3315	Foundries
3331	Ag., construction, and mining machinery mfg.
3332	Industrial machinery manufacturing
3333	Commercial and service industry machinery
3336	Turbine and power transmission equipment mfg.
3339	Other general purpose machinery manufacturing
3341	Computer and peripheral equipment mfg.
3342	Communications equipment manufacturing
3343	Audio and video equipment manufacturing
3344	Semiconductor and electronic component mfg.
3345	Electronic instrument manufacturing
3346	Magnetic media manufacturing and reproducing
3351	Electric lighting equipment manufacturing
3352	Household appliance manufacturing
3353	Electrical equipment manufacturing
3359	Other electrical equipment and component mfg.
3361	Motor vehicle manufacturing
3362	Motor vehicle body and trailer manufacturing
3363	Motor vehicle parts manufacturing
3364	Aerospace product and parts manufacturing
3365	Railroad rolling stock manufacturing
3366	Ship and boat building
3369	Other transportation equipment manufacturing
3391	Medical equipment and supplies manufacturing

NAICS code	NAICS title
3399	Other miscellaneous manufacturing
5112	Software publishers
5152	Cable and other subscription programming
5172	Wireless telecommunications carriers
5174	Satellite telecommunications
5179	Other telecommunications
5182	Data processing, hosting and related services
5191	Other information services
5413	Architectural and engineering services
5415	Computer systems design and related services
5416	Management and technical consulting services
5417	Scientific research and development services
6215	Medical and diagnostic laboratories
Advanced business & health services	
5221	Depository credit intermediation
5222	Nondepository credit intermediation
5223	Activities related to credit intermediation
5231	Securities and commodity contracts brokerage
5239	Other financial investment activities
5241	Insurance carriers
5242	Insurance agencies and brokerages
5251	Insurance and employee benefit funds
5259	Other investment pools and funds
5411	Legal services
5412	Accounting and bookkeeping services
5414	Specialized design services
5418	Advertising, PR, and related services
5419	Other professional and technical services
5511	Management of companies and enterprises
5611	Office administrative services
5614	Business support services
6214	Outpatient care centers
6216	Home health care services
6219	Other ambulatory health care services
6221	General medical and surgical hospitals
6222	Psychiatric and substance abuse hospitals
6223	Other hospitals
6231	Nursing care facilities
6232	Residential mental health facilities

Appendix B: Assessing Pittsburgh's industry and academic core competencies to support innovation-led development

From a regional economic development perspective, local "core competencies" represent a critical mass of know-how.[42] The competencies are represented by the expertise and creative activity across product development and process improvements in industry, as well as by the advancement of scholarly activity and technology transfer and the creation of pools of specialized talent in the region's research institutions.

This appendix presents details of a core competency analysis undertaken for the Pittsburgh region. The analysis involved an in-depth quantitative investigation of documented innovation-related output (patents and publications) by local industry and research institutions. This quantitative data study was supplemented by one-on-one interviews with industry executives and senior leadership and leading faculty at Pittsburgh research institutions to gather further intelligence and guidance on the focus of research and innovation activity.

Patent analysis

A classic indicator of core technology competencies is patent innovation activity. Patents are a primary means for inventors to protect their product innovations from being copied, and as such can be a good proxy for market-ready innovation. Although there are other forms of intellectual property protection through copyrights, trademarks, and trade secrets, patents are among the most widely used form of protection of novel technological inventions.

The analysis of patent innovation activity focuses only on patents invented by Pittsburgh residents in order to more precisely measure the innovation generated within the region rather than the innovations that Pittsburgh companies import from outside inventors as assignees of intellectual property. Because it can take several years from the time of initial application for a patent award to be issued, the analysis also considers patent awards along with patent applications in order to provide a more current assessment of recent innovation activities.

The 17,000-plus patent awards and applications filed by inventors residing in Pittsburgh from 2009 to 2015 constitute a significant database to consider innovation activity in the region. While the University of Pittsburgh (Pitt) and Carnegie Mellon University (CMU) were among the top five patent generators in Pittsburgh—with a combined 839 patent awards and applications over the 2009 to 2015 period—the vast majority of patent generation is affiliated with industry.

Leading patent areas

To identify where Pittsburgh stands out in patent innovation activity, the analysis first considered those specific patent classifications where Pittsburgh is a national leader based on a strong standing in *specialization* and *quality* within specific technology areas:

- **Patent specialization** is measured by whether a patent classification area has a higher level of concentration in the Pittsburgh region than in the nation relative to overall patenting volume.
- **Patent quality** is measured by whether a patent classification area has a higher level of citations per patent in that classification area than the national average. This metric can be viewed as a measure of patent impact in terms of contributing to follow-on innovation activity. By routinely citing prior patents as references in documenting their new intellectual property, patentees demonstrate the influence and importance of these earlier patents on future innovation.

Pittsburgh stands out as a national leader in 93 patent classification areas by having both a higher level of concentration and a higher level of citations. These patent classification areas reflect detailed areas of innovation in certain technology platforms in which Pittsburgh stands out and can also be grouped together in broader innovation categories.

These leading patent classifications fall into 14 broader innovation categories, reflecting multiple leading patent classifications (Table B-1). Six of these categories had substantial numbers of patents:

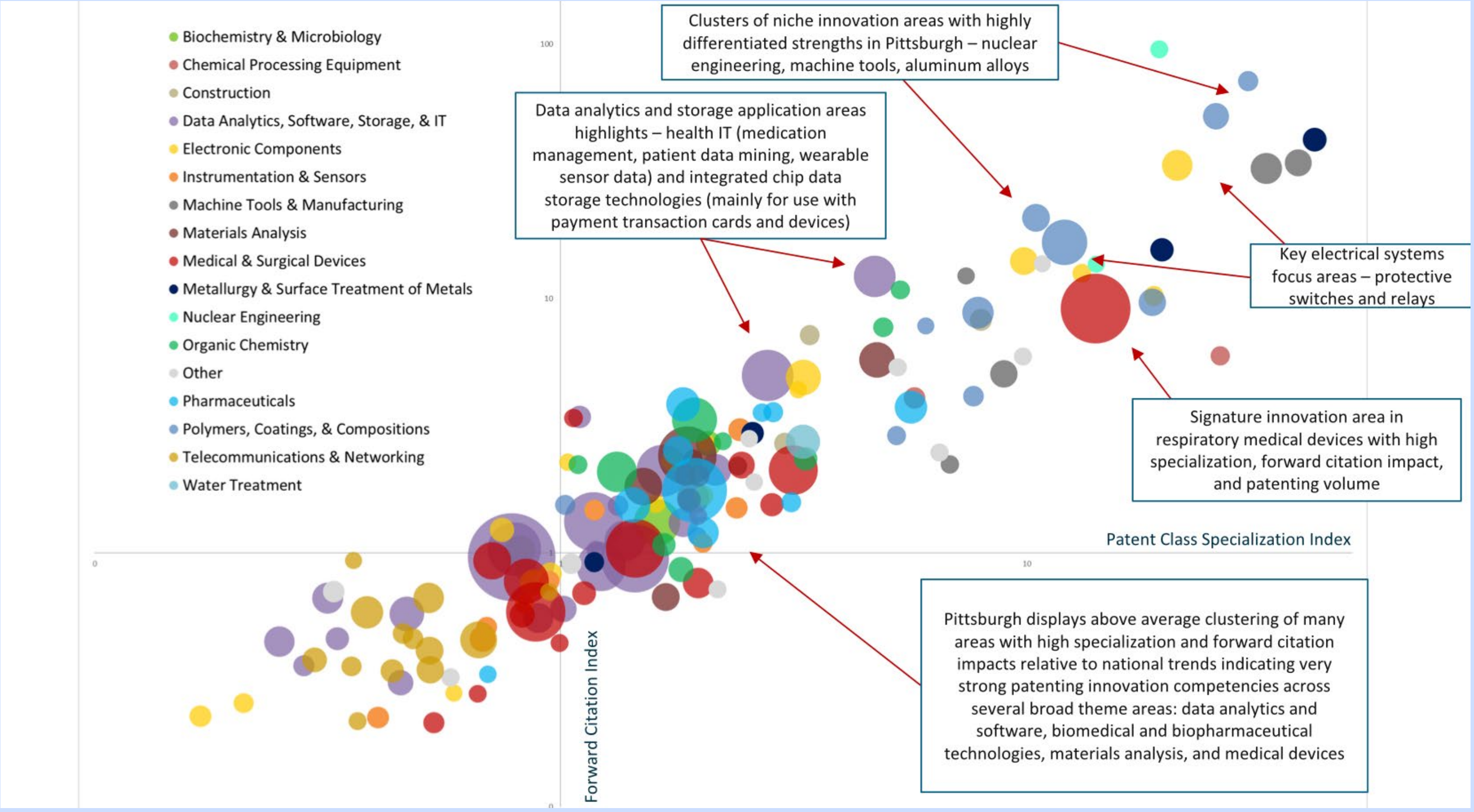
- Data analytics, software, storage, and information technology.
- Medical and surgical devices.
- Pharmaceuticals.
- Polymers, coatings, and compositions.
- Materials analysis.
- Electronic components.

Table B-1: Broad technology categories of leading patent innovation areas by total number of patents and number of patent classifications

Broad categories of leading patent innovation areas	Total number of patents	Number of patent classifications
Data analytics, software, storage, & IT	1055	11
Medical & surgical devices	927	9
Pharmaceuticals	721	9
Polymers, coatings, & compositions	505	11
Materials analysis	433	4
Organic chemistry	415	8
Electronic components	394	11
Machine tools & manufacturing	231	6
Biochemistry & microbiology	188	2
Chemical processing equipment	127	3
Instrumentation & sensors	121	4
Metallurgy & surface treatment of metals	109	3
Construction	91	3
Nuclear engineering	42	2
No categories	207	7
Total	5566	93

Source: Thomson Innovation, calculations by TEConomy Partners.

Figure B-1: Mapping of Pittsburgh patent innovation based on specialization and forward citation rating, 2009-2015



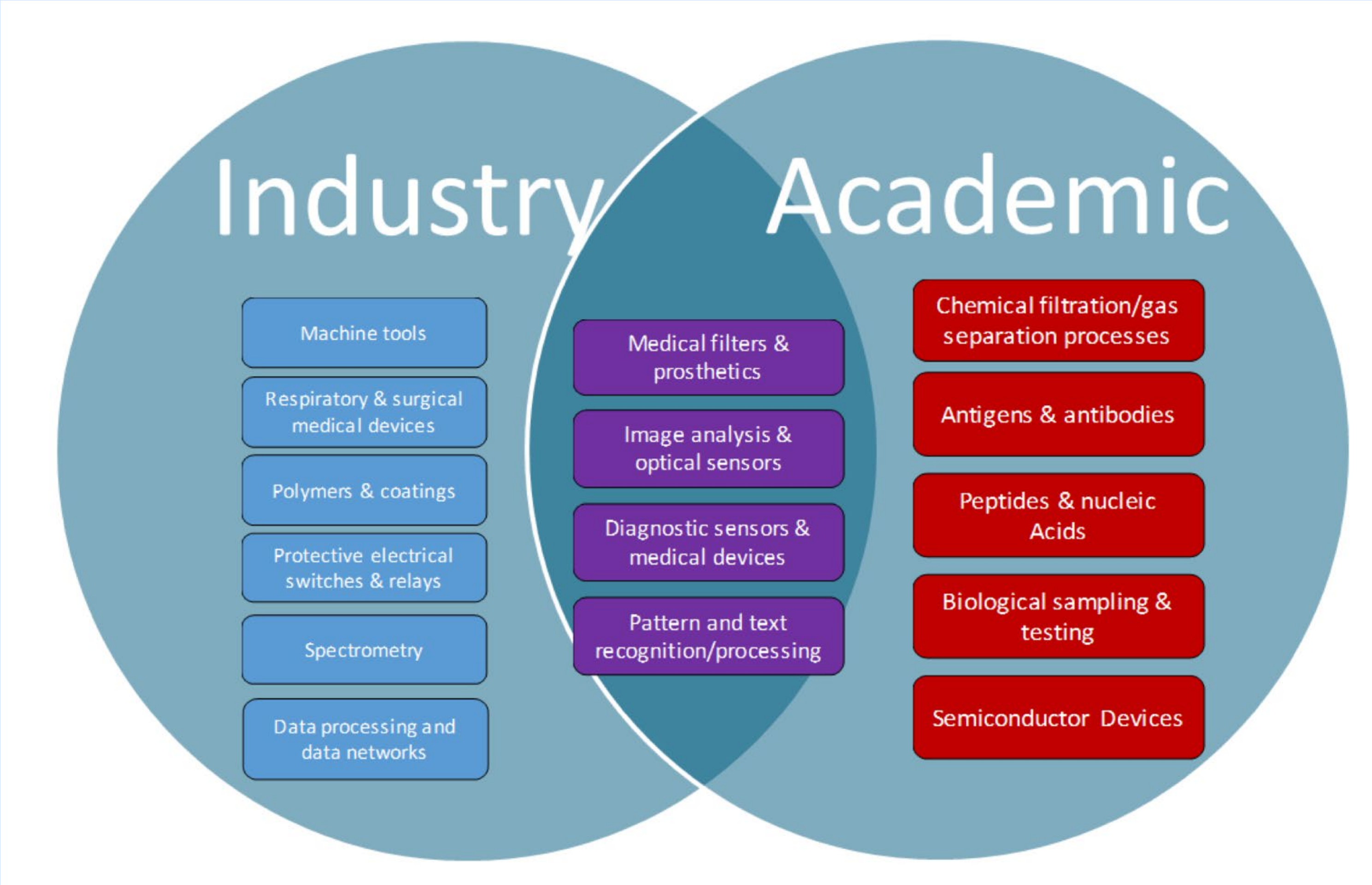
Source: U.S. Census Bureau, American Community Survey, authors' calculations.

Despite having high levels of patents and citations in broad industry categories, Pittsburgh's highest levels of specialization and quality (citation rates) are found among the smaller categories of leading innovation areas, such as machine tools, nuclear engineering, and metallurgy, which suggests strong innovation niche focuses for the region in related technologies. Figure B-1 presents a comprehensive mapping of the levels of patent specialization (horizontal axis) and citation rates (vertical axis) across all patent innovation classifications. Each bubble represents a specific patent classification, and the color of the bubble shows the corresponding broad category of patent innovation to which that classification belongs. Those patent classifications located more toward the upper-right-hand quadrant represent the top leading areas of patent innovation, since their specialization and forward citation impact outpaces overall trends in the United States in the six-year period.

Across the full set of leading patent classifications, a closer examination suggests that there are distinct areas of industry and university strengths within different leading innovation areas, with only a few shared areas of focus. Based on the mix of patent generation across industry and universities, it is possible to assess those leading patent classifications that represent industry, university, or shared strengths. Given that only 8 percent of the total patent activity in Pittsburgh is driven by universities, we used the following thresholds to assess the mixture of industry versus university concentration:

- University strengths were those leading patent classifications where more than 20 percent of the patents were generated from universities, or more than double the overall average.
- Industry strengths were those leading patent classifications where less than 10 percent were university-led or more than 90 percent were industry-led patents.
- Shared industry-university strengths were those leading patent classifications where university patents made up

Figure B-2: Leading patent classifications by industry, universities, or both (shared strength) compared to U.S. overall



between 10 percent and 20 percent of the patents and industry also had a significant share.

Figure B-2, which details the overlap between industry and university focus areas, suggests that industry dominates in more advanced manufacturing innovation areas, while the university patent focus is primarily in biological and chemistry fields, with some areas of focus in electronics. However, in a number of leading patent invention areas there is a substantial overlap in industry and university activity, which may indicate the presence of bridging technologies. These shared areas of industry and university strength turn out to be highly relevant to the concept of "smart manufacturing," or the use of information technology and data within the production process. These areas include pattern recognition, sensors, and image analysis.

Patent network analysis

The idea of bridging technologies is a powerful concept not just for connecting industry and university strengths but for assessing networks of patent innovation formed by the patterns of forward innovation that occur as patents age. The economic literature describing healthy innovation ecosystems suggests that the formation of such networks is one of the critical underpinnings of a robust innovation economy.

It is possible to identify networks across patent innovation within a region by analyzing the linkages of forward citations from a patent population of interest. Forward citations occur when a new patent filed cites a prior patent as a reference in documenting the new intellectual property created. This routinely occurs since the prior referenced patents usually contain fundamental ideas and concepts used in developing the new intellectual property of more recent patents. The original patent is thus said to generate forward citations in all patents that reference it.

Using network analysis algorithms, it is possible to construct networks of active linkages in patent activities across different Pittsburgh companies and research institutions based on the citation patterns of patents. The relationships reflected in the forward citations of patents serve to highlight where there are close innovation relationships and clusters of innovation activity taking place in Pittsburgh.

Pittsburgh's patenting innovation landscape as described by the network of forward citation activity can be described as having a set of core patent innovation clusters that are highly interconnected, along with more focused niche patent clusters that are more stand-alone. Six core patent innovation networks were identified by the analysis of forward linkages:

- Polymers and coatings.
- Data storage devices (e.g., hard drives) and related infrastructure.
- Data analytics (with focus around finance, e-commerce), network operations and security, and software.
- Image analysis technologies (with focus around spectroscopy), optic sensors, and interactive image displays.
- Bioscience applications in pharmaceuticals and biochemistry.
- Medical devices (with focus areas in respiratory and spinal stabilization applications).

In addition, there were four more-focused patent innovation networks, including:

- Construction, well drilling, and other industrial treatment processes (e.g., water treatment).
- Electronics applications in semiconductor manufacturing/coatings, fuel cells, and connectors.
- Industrial milling and machining tools.
- Electrical switches and relays (with focus on protective and high-load applications).

A graphic illustration of these patent innovation networks is presented in Figure B-3, where each bubble represents different patent classifications coded based on broad technology focus areas; the lines show the connections from forward citation relationships between all the patent areas. The density of the connections among the core patent innovation networks is reflected in the tight links and proximity of the patent areas. What is also revealed in Figure B-3 among the core patent innovation networks is the connector or bridge role played by the patent innovation network of image analysis and optics, which corresponds closely to the leading patent classifications that are shared industry and university strengths. This can be observed in Figure B-3 by how the purple bubbles associated with image analysis and optics are found across the core patent innovation network areas and have dense connections to many other multidisciplinary technology areas. Additional analysis of network centrality across patent classifications confirms this bridging role of image analysis and optics technology platforms. It also suggests that two technology focuses related to the patent innovation network of image analysis and optics stand out as the foundation for connecting applications across the core patent innovation areas:

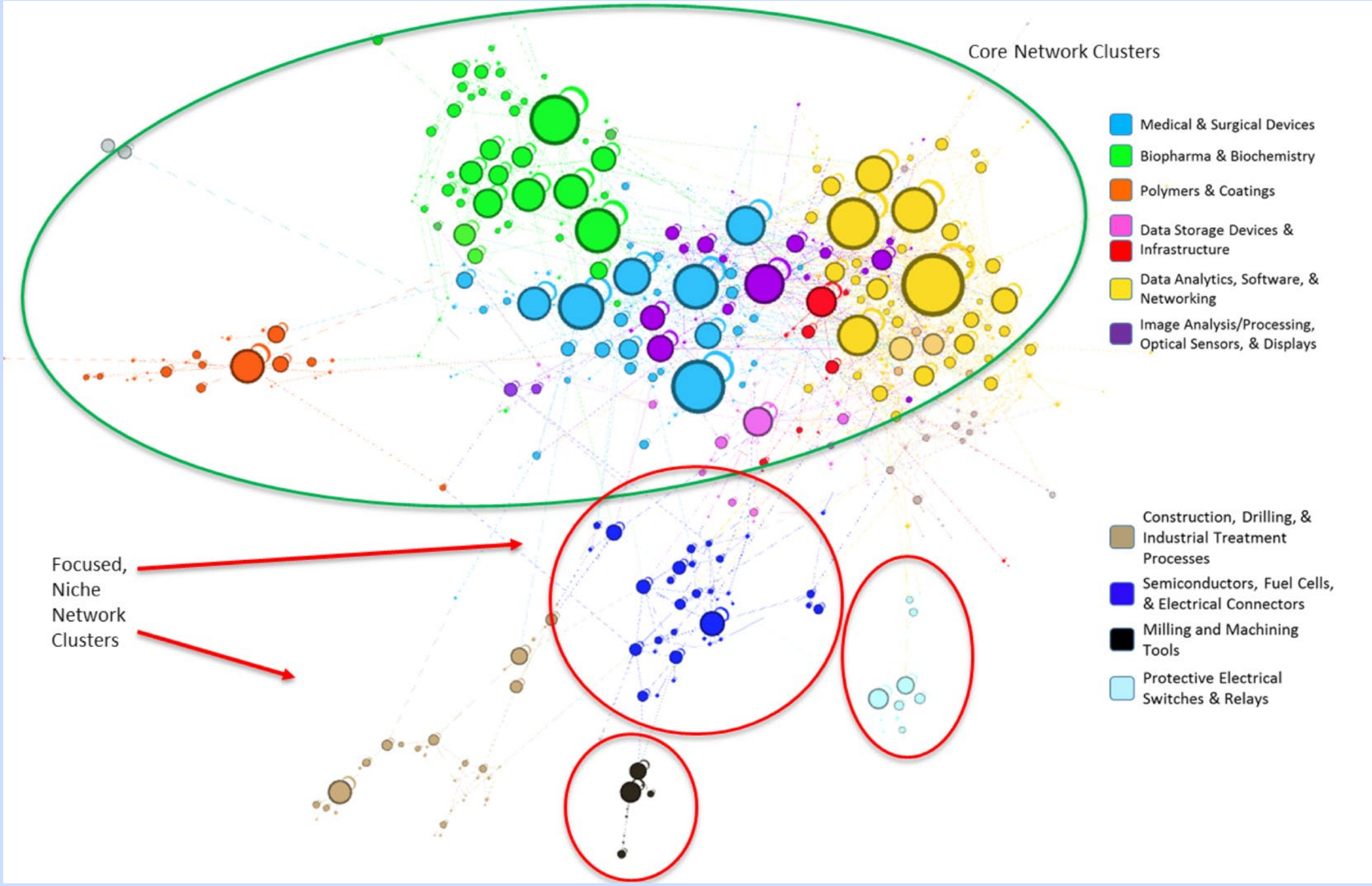
- Image analysis techniques (via pattern recognition, screening, machine learning, etc.) and image data storage (big data storage and access).
- Materials analysis technologies, revolving primarily around optic sensing applications such as spectroscopy.

It is also important to note that the niche focus patent innovation areas spanning nuclear engineering, machine tools, and some electronics, while highly compartmentalized, are also clearly linked to some of the top-performing leading patent classifications in terms of specialization and quality.

Summary of patent analysis

The analysis of patent activity in Pittsburgh suggests a wide

Figure B-3: Mapping of patent innovation networks found in Pittsburgh through forward citation analysis



Source: Thomson Innovation, calculations by TEConomy Partners.

range of innovation capabilities that can be counted as national leaders and regional innovation networks. These leading patent innovation areas include data analytics, data storage, polymers and coatings, pharmaceuticals, and medical and surgical devices.

Another leading and highly interconnected regional patent innovation area, image analysis and optics, is playing a strong bridging role in connecting several major innovation capabilities in Pittsburgh and represents a shared strength across industry and university patent activities. This bridging innovation strength in image analysis and optics is a foundation, together with data analytics and pattern recognition, in transformative innovations involving smart manufacturing, digital health, autonomous systems, and the Internet of Things. It suggests that Pittsburgh, by being linked to advanced manufacturing technologies and advanced biomedical technologies, is well positioned to be a national leader in these transformations.

At the same time, a number of niche innovation areas, with a smaller number of patents, have especially high levels of patent specialization and quality that represent more isolated, stand-alone networks in Pittsburgh. These niche innovation areas include nuclear engineering, machine tools, and some electronics, and they represent areas of specialization in which the region has unique expertise and capabilities.

Another way to view the significance of Pittsburgh's strengths as a national leader in patent activity and in regional innovation networks is to map its position in patent activity to the advanced industries driving the regional economy. Table B-2 presents this mapping and suggests a strong alignment of patent innovation strengths and advanced industries critical to the region's success.

This mapping suggests that for many of the advanced industries found in Pittsburgh, there is a strong connection to patent innovation strengths and networks in the region.

Academic research strengths

Another cornerstone to a region's core technology competencies is the strength of its research institutions. Pittsburgh has a robust academic research base that generates more than $1.1 billion in annual research expenditures across Pitt, CMU, and Duquesne University. On a per capita basis, Pittsburgh stands 263 percent higher than the national average. Despite its existing size and

Table B-2: Mapping of leading patent innovation classifications and networks by advanced industry clusters

Advanced industry clusters	Crosswalk of innovation activity in Pittsburgh	
	Where is Pittsburgh a leader in patent activity?	Where does Pittsburgh have strong connections across patent areas?
Automation and industrial machinery	Tools for boring/drilling machines, milling cutters; navigation controls	Industrial milling and machining tools
Chemicals, polymers, and other non-metal materials	Polymers, coating compositions, chemical filtration processes	Polymers and coatings
Computing, networking, information services, and internet applications	Data processing, data networks	Data storage devices and infrastructure; data analytics, software, and networking; image analysis technologies
Corporate services	n/a	n/a
Electronics manufacturing	Protective and high-capacity switches and relays, semiconductors using organic materials, optical sensors	Semiconductors, fuel cells, and electrical connectors; electrical switches and relays
Energy	Nuclear engineering	
Engineering, commercial research, and technical services		Construction, well drilling, and industrial treatment processes
Finance and insurance	Finance analytics products	Data analytics, software, and networking
Health services	Health IT	Data analytics, software, and networking; image analysis technologies
Medical technology	Biopharmaceuticals, respiratory devices, infusion devices, wearable sensors	Medical and surgical devices, bioscience applications in pharmaceuticals and biochemistry
Metals & metal processing	Aluminum alloys	

strength, the Pittsburgh academic research base is quite dynamic, growing considerably faster than the U.S. average, with gains of 31 percent from 2009 to 2014 compared to 17 percent nationally.

While not all academic research leads to new breakthrough discoveries and commercialization activities that can be measured in terms of patent innovation and startup companies, it does support the talent and infrastructure needed to become world class in core technology competencies. The success of Pittsburgh research universities in winning competitive research funding is an important generator of scientific expertise, new talent generation of graduate and post-doctoral students, and advanced facilities that can often be important to economic development.

4. Fifteen research fields stand out with more than $10 million in annual research expenditures in Pittsburgh, led by medical sciences with $529 million, biological sciences with $171 million, and computer sciences with $118 million (see Table B-3).

While absolute size matters, not all research fields receive the same level of funding at the national level. One way to measure the excellence of Pittsburgh in research activity is to consider where it stands out compared to the national concentration of research activity, measured by a research location quotient. Two of the large research areas in Pittsburgh stand out in this regard: computer sciences has six times the national research concentration level, and medical sciences has 1.5 times the national research concentration level. But other research fields also stand above the national research concentration level, including psychology, other life sciences (public health, nursing, etc.), multidisciplinary engineering, bioengineering, chemical engineering, and mathematical sciences.

Another way to consider the strengths of academic research expenditures beyond total funding and relative concentration is growth rates. Among the large research fields, computer science and biological sciences exceeded national growth from 2009 to 2014, while medical sciences did not keep pace. It is likely, though, that much of the increase in biological sciences was due to changes in reporting; the combined medical and biological sciences grew a robust 29 percent in Pittsburgh, compared to 14 percent nationally. Other research strengths in Pittsburgh that are outpacing the nation include other life sciences, psychology, and mathematical sciences. What is revealing from the growth rates is that there are a number of emerging research fields, including environmental sciences, mechanical engineering, and physics.

Table B-3: Leading research fields in Pittsburgh by research expenditure, 2009-2014

Research field	2009 ($ thousands)	2014 ($ thousands)	2014 location quotient	2014 per capita share compared to the national average	Pittsburgh percentage change, 2009-2014	U.S. percentage change, 2009-2014
Medical sciences	515,255	528,529	1.53	345%	2.60%	13.50%
Biological sciences	28,447	171,048	0.87	198%	501.30%	15.40%
Computer sciences	95,305	117,598	3.65	825%	23.40%	20.40%
Other life sciences	15,644	40,182	1.11	252%	156.90%	60.10%
Other engineering	35,074	38,999	1.16	262%	11.20%	4.10%
Psychology	15,433	22,945	1.2	272%	48.70%	17.30%
Chemistry	22,578	22,771	0.79	179%	0.90%	9.00%
Electrical engineering	22,187	22,708	0.55	124%	2.30%	34.30%
Bioengineering	14,688	18,468	1.16	262%	25.70%	47.00%
Physics	12,098	16,708	0.49	110%	38.10%	9.90%
Chemical engineering	12,380	14,988	0.99	224%	21.10%	30.30%
Environmental sciences	3,946	12,517	0.23	52%	217.20%	11.10%
Mechanical engineering	9,172	12,151	0.48	109%	32.50%	21.20%
Mathematical sciences	6,007	11,180	1.02	230%	86.10%	20.20%
Civil engineering	8,029	10,495	0.5	113%	30.70%	28.10%

Source: Web of Science.

Yet another way to consider research excellence is through analysis of the collection of peer-reviewed publications generated by researcher talent at the region's universities. This metric offers a broader view of competitive standing in scholarly activity.

A key advantage of an analysis of peer-reviewed publications is that it reflects more detailed fields of research than can be obtained through the reporting by research expenditures. Thomson Innovation's Web of Science database tracks publications in peer-reviewed journals for universities in over 250 fields involving basic, applied, and clinical research.

To identify excellence in Pittsburgh, it is important not to focus solely on the volume of peer-reviewed publications across fields, since the number of journals can vary substantially by publication field, and some fields, such as physics, tend to have more multiple authors on publications. For instance, there were over 13,000 publications in the critical care field nationally, compared to just 2,800 in the robotics field. While the number of publications is an indication of the number of faculty involved, it does not provide insights into the areas of scholarly activity in which Pittsburgh stands out compared to the nation. As with research expenditures, a way to consider Pittsburgh's distinct fields of national leadership in scholarly activity is to derive a publication location quotient, i.e., measure where the city has a higher concentration of publication activity compared to the nation.

In the number of peer-reviewed publications, the breadth of scholarly activity across Pittsburgh's academic institutions is revealed by 136 publication fields having at least 100 publications from 2009 to 2015 (Table B-4). The top fields in numbers of publications are primarily found in the life sciences, with surgery, neurosciences, oncology, and molecular biology/biochemistry each having over 2,000 publications from 2009 to 2015. This corresponds to the high level of research funding in medical and biological sciences in Pittsburgh. Still, among the 20 top fields in number of publications are several outside of life sciences, including particle physics, astronomy, material science, electrical engineering, and multidisciplinary chemistry.

Pittsburgh also stands out in having 80 publication fields with a higher level of specialization than the nation. Of these, the top 20 fields in publication location quotient each had more than 1.70 times the national average. Among the top leaders is a more diverse grouping of publication fields—robotics, gerontology, particle physics, critical care medicine, transplantation, psychiatry, and computer science/artificial intelligence—showing the diverse areas of distinct excellence found across Pittsburgh's academic institutions.

It is interesting to note that among the top 20 publication fields in Pittsburgh, there are few fields that lead in both number of publications and publication location quotient. This suggests that examining both measures offers insights into Pittsburgh's areas of strength in scholarly activity.

Table B-4: Top 20 publication fields in Pittsburgh by number of publications and publication location quotient, 2009-2015

Publication field	Number of publications	Publication field	Publication location quotient
Surgery	2,621	Robotics	4.46
Neurosciences	2,599	Gerontology	3.81
Oncology	2,094	Physics Particles Fields	3.59
Biochemistry Molecular Biology	2,081	Critical Care Medicine	3.41
Clinical Neurology	1,853	Transplantation	2.95
Multidisciplinary Sciences	1,727	Psychiatry	2.32
Psychiatry	1,697	Computer Science Artificial Intelligence	2.25
Physics Particles Fields	1,608	Psychology Developmental	2.11
Astronomy Astrophysics	1,542	Cell Tissue Engineering	2.04
Materials Science Multidisciplinary	1,434	Computer Science Software Engineering	2.03
Immunology	1,417	Rheumatology	2.01
Cell Biology	1,316	Otorhinolaryngology	1.99
Chemistry Physical	1,242	Neuroimaging	1.99
Engineering Electrical Electronic	1,144	Pathology	1.91
Endocrinology Metabolism	1,139	Respiratory System	1.88
Medicine Research Experimental	1,135	Physics Nuclear	1.77
Public Envir/Occupational Health	1,122	Psychology Clinical	1.77
Chemistry Multidisciplinary	1,071	Obstetrics Gynecology	1.75
Pharmacology Pharmacy	1,069	Engineering Biomedical	1.75
Cardiac Cardiovascular Systems	1,034	Rehabilitation	1.72

Source: Web of Science.

Interviews with research leaders from Pitt, CMU, and Duquesne and national rankings from *U.S. News & World Report* confirm the breadth of research excellence found in Pittsburgh's academic institutions.

- Interviews noted many areas of excellence that stand out across computer sciences, life sciences, material sciences, and energy:
  * Computer sciences—machine learning, robotics, cyber-physical systems (Internet of Things), information assurance.
  * Life sciences—cell and tissue engineering, rehabilitation, lung and respiratory systems, critical care, transplantation, women's health, oncology, infection and immunity, personalized medicine, and bioinformatics.
  * Materials—metals and additive manufacturing, soft materials, membrane materials, product design.
  * Energy—energy materials, smart grid.
- *U.S. News & World Report* rankings have Pittsburgh academic institutions among the top 20 in many fields:
  * 1st in computer sciences overall, including 1st in programming languages, 2nd in computer engineering, and 4th in computer systems (CMU)
  * 2nd in robotics (CMU)
  * 5th in women's health (Pitt/UPMC)
  * 8th in drug and alcohol abuse (Pitt/UPMC)
  * 8th in electrical engineering (CMU)
  * 8th in mechanical engineering (CMU)
  * 9th in pediatrics (Pitt/UPMC)
  * 10th in geriatrics (Pitt/UPMC)
  * 11th in material sciences (CMU)
  * 18th in bioengineering (Pitt)

In sum, the prominence of Pittsburgh's academic research institutions is suggested across an analysis of research funding, publication activities, national rankings, and leadership interviews. While life sciences and computer sciences stand out in excellence, other academic research strengths are also apparent, especially in material sciences, engineering, and energy. The multidisciplinary nature of Pittsburgh's academic research strengths also is revealed through standout fields such as robotics and biomedical engineering.

Alignment of core competencies with advanced industry clusters in Pittsburgh

The significance of Pittsburgh's strengths in patent activity and academic research for innovation-led development is illustrated by an alignment with advanced industry clusters that drives the regional economy. Table B-2 (on page 61) presents this mapping for patent innovation strengths and networks found, while Table B-6 maps this alignment across dimensions of research funding, publication activities, national rankings, and leadership interviews.

The implications of this strong alignment between patent innovation activity/academic research and the advanced industry clusters is that Pittsburgh is well-positioned to compete based on its innovative capacities across nearly all of its advanced industry clusters. This is a formidable position that opens many opportunities, particularly as advanced technological solutions become more and more interdisciplinary and involve increased industry-university partnerships.

Table B-6: Mapping of academic research strengths found in Pittsburgh to advanced industry clusters

Industry cluster	Research funding	Publications activities	National rankings	Leadership interviews
Automation and industrial machinery	*Mechanical engineering* ($12m, 33% growth, faster than nation)	*Robotics* (4.46 LQ) *Automation control systems* (1.30 LQ)	*Robotics* (CMU 2nd)	Robotics
Chemicals, polymers, and other materials	*Chemical engineering* ($15m)	*Physical chemistry* (1,242 pubs) *Multi-disciplinary materials science* (1,434 pubs)		Soft materials, membrane materials
Computing	*Computer sciences* ($117 m, 3.65 LQ, 23% growth, faster than nation)	*Artificial intelligence* (2.25 LQ) *Software engineering* (2.03 LQ) *Information systems* (1.46 LQ)	*Computer sciences* (CMU 1st)	Cyber-physical systems
Corporate services	n/a	Management (1.28 LQ)	--	--
Electronics manufacturing	*Electrical engineering* ($23m)	*Electrical engineering* (1,144 pubs)	*Electrical engineering* (CMU 8th)	
Energy	Part of *other engineering* ($39m, 1.16 LQ, 11% growth, faster than nation)	*Nuclear physics* (1.77 LQ)		Energy materials, cyber-physical systems (smart grid)
Engineering, research, and technical services	Engineering ($126m, 0.69 LQ, 15% growth, slower than nation)	Operations research (1.60 LQ)	*Electrical engineering* (CMU 8th)	
Finance and insurance	n/a	n/a	n/a	--

Industry cluster	Research funding	Publications activities	National rankings	Leadership interviews
Health services	*Medical and biological sciences* ($700 m, 1.29 LQ, 30% growth, double U.S. average growth) *Other life sciences* ($40m, 1.11 LQ, 157% growth, faster than nation)	*Numerous clinical research fields* *Medical informatics (1.46 LQ)*	*Women's health* (5th), *drug & alcohol abuse* (8th), *pediatrics* (9th), *geriatrics* (10th)	Lung and respiratory systems, critical care, transplantation, women's health, oncology, infection and immunity, and personalized medicine
Medical technology	*Medical and biological sciences* ($700 m, 1.29 LQ, 30% growth, double U.S. average growth) *Bioengineering* ($18m, 1.16 LQ, 26% growth, slower than nation)	*Cell and tissue engineering* (2.04 LQ) *Biomedical engineering* (1.75 LQ) *Biomaterials* (1.58 LQ) *Biochemistry/molecular biology* (2,081 pubs) Cell biology (1,316 pubs) Immunology (1,417 pubs, 1.44 LQ) *Pharmacology* (1,069 pubs) *Neuroimaging* (1.99 LQ) *Medical lab tech* (1.46 LQ) *Numerous clinical research fields*		Cell and tissue engineering, rehabilitation, and bioinformatics
Metals & metal processing	Part of *other engineering* ($39m, 1.16 LQ, 11% growth, faster than nation)	*Metallurgy* (1.47 LQ)		Metals and additive manufacturing

Endnotes

1. Bill Toland, "In Desperate 1983, There Was Nowhere for Pittsburgh's Economy to Go but Up," *Pittsburgh Post-Gazette*, Dec 23, 2012.

2. Robert T. Atkinson, "The Past and Future of America's Economy: Long Waves of Innovation That Power Cycles of Growth" (Cheltenham, England: Edward Elgar, 2005).

3. McKinsey Global Institute, "Disruptive Technologies: Advances That Will Transform Life, Business, and the Global Economy" (2013), http://www.mckinsey.com/businessfunctions/digital-mckinsey/our-insights/disruptivetechnologies.

4. Joseph A. Schumpeter, "Capitalism, Socialism and Democracy: Third Edition" (Mansfield Centre, Conn.: Martino, 2011).

5. For a definition of advanced industries, see Jonathan Rothwell et al., "America's Advanced Industries: What They Are, Where They Are, and Why They Matter" (Washington: Brookings Institution, 2015).

6. The figures were calculated by taking the location quotient of employment in software development (NAICS 5112), Pharmaceutical preparation (NAICS 3254), and Research and Development in Biotechnology (NAICS 5417), and determining what the overall employment levels would be if these industries had LQs equal to R&D LQs in computer science, cell and tissue biology, and overall medical research. For example, the software industry employs 1,712 workers in the Pittsburgh metropolitan area, equaling an LQ of .65, while the region has 365 percent the national average in computer science university R&D. If employment equaled 365 the national average, there would be 9,669 more workers.

7. McKinsey, "Disruptive Technologies."

8. James Dias, "Six Big Benefits of Applying Automation to Healthcare," HIT Consulting, July 2014, http://hitconsultant.net/2014/07/21/6-big-benefits-of-applying-automation-to-healthcare/

9. Bruce Katz and Julie Wagner, "The Rise of Innovation Districts: A New Geography of Innovation in America" (Washington: Brookings Institution, 2014).

10. National Science Foundation, "Higher Education and Research Development Survey: Fiscal Year 2015," November 15, 2016, https://ncsesdata.nsf.gov/herd/2015/.

11. "Overview: UPMC," *U.S. News and World Report,*2017," http://health.usnews.com/best-hospitals/area/pa/upmc-university-of-pittsburgh-medical-center-6230029.

12. For example, Pitt ranks fifth, ninth, and 16th in women's health, pediatrics, and medical research, respectively, and CMU ranks first, second, and fifth in computer science, computer engineering, and engineering, according to *US News & World Report*.

13. *U.S. News & World Report*, "Graduate Schools Rankings: Computer Science, 2014," https://www.usnews.com/best-graduate-schools/top-science-schools/computer-science-rankings; "Graduate Schools Rankings: Computer Engineering, 2017," https://www.usnews.com/best-graduate-schools/top-engineering-schools/computer-engineering-rankings.

14. University of Pittsburgh Medical Center, "Public Offering of Evolent Health Is a Win for Co-Founder UPMC," 2015, http://www.upmc.com/media/NewsReleases/2015/Pages/evolent-ipo.aspx.

15. Innovation Works, "A Snapshot of Pittsburgh's Technology Landscape: Trends and Highlights, 2012-16," https://www.innovationworks.org/Portals/1/documents/Pittsburgh%27s%20Technology%20Investment%20Landscape%202012-2016.pdf.

16. Jonathan Rothwell, "The Hidden STEM Economy" (Washington: Brookings Institution, 2013), https://www.brookings.edu/research/the-hidden-stem-economy/.

17. As stated by several firm and workforce development institution interviews.

18. Partner4Work, "Labor Market Demand: January 2017," https://www.partner4work.org/uploads/monthly-labor-january-17.pdf.

19. "Pittsburgh Medical Device Firm Relocates to Raleigh,"*BizJournal*, January, 2016, http://www.bizjournals.com/pittsburgh/blog/the-next-move/2016/02/pittsburgh-medical-device-firm-relocating-to.html

20. For additional information on life sciences industry development see "Pittsburgh Region Life Sciences Benchmarking & Gaps Analysis," prepared for the University of Pittsburgh, July 18, 2016.

21. Forward citations of patents demonstrate the influence and importance of these earlier patents on future innovation and can show the connections across innovation drivers in a region.

22. See Appendix B for more information.

23. Kauffman Index: Metropolitan Area Rankings, (Kansas City: Kauffman Foundation, 2016). http://www.kauffman.org/microsites/kauffman-index/rankings/metropolitan-area?Report=GrowthEntrepreneurship&Indicator=Rank

24. Inc. 5000, 2017.

25. Startups and patents are taken as a share of research expenditure.

26. Peer institutions are defined as those universities with a medical school with research expenditures between $50 million and $100 million, as reported by the Association of University Technology Managers.

27. Innovation Works and Ernst & Young, "A Snapshot of Pittsburgh's Technology Investment Landscape: Trends and Highlights, 2012-16."

28. Burning Glass Technologies, Council for Adult and Experiential Learning, and Allegheny Conference on Community Development, "Inflection Point: Supply, Demand, and the Future of Work in the Pittsburgh Region," 2016, http://www.alleghenyconference.org/wp-content/uploads/2016/08/InflectionPoint.pdf.

29. Ibid

30. Ibid

31. Partner4Work, "Job Seeker Trends in Selected Pittsburgh Neighborhoods," 2015, https://www.partner4work.org/uploads/job-seeker-trends_4-neighborhoods.pdf.

32. Appendix C offers a more in-depth description of the context, existing relevant programs, and specifics of each strategy.

33. See Lu, Morris, and Frechette, "Current Standards Landscape for Smart Manufacturing Systems," NISTIR 8107, February 2016.

34. Rob Atkinson and Stephen Ezell, *Innovation Economics: The Race for Global Advantage* (New Haven, Conn.: Yale University Press, 2012), p. 130.

35. See Figure 1.1 in Congressional Budget Office, *Federal Policies* and Innovation, November 2014, p. 6.

36. Paul Bauer et al., "State Growth Empirics: The Long-Run Determinants of State Income Growth," Working Paper #6, Federal Reserve Bank of Cleveland, 2006.

37. Jonathan Rothwell et al., "America's Advanced Industries: What They Are, Where They Are, and Why They Matter" (Washington: Brookings Institution, 2015), p. 11.

38. Rothwell et al., p. 11.

39. Council on Competitiveness and National Governors Association, *Innovation America: Cluster-Based Strategies for Growing State Economies*, 2007, p. 1.

40. For a discussion of industry cluster theory, see the National Research Council report, *Best Practices in State and Regional Innovation Initiatives*, 2013, pp. 31–34.

41. Industry employment data at the six-digit level of the North American Industry Classification System (NAICS) were used based on an enhanced database from IMPLAN. These data are based on the U.S. Bureau of Labor Statistics' Quarterly Census of Employment and Wages (QCEW), supplemented by County Business Patterns and other regional data sets. Employment

data used in the analysis include full-time and part-time positions.

42. The concept of core competencies is now widely understood as a critical factor for industries to be competitive. As defined by Gary Hamel and C.K. Prahalad in *Competing for the Future*, a "competence is a bundle of skills and technologies representing the sum of learning across individual skill sets and organizational units." See G. Hamel and C.K. Prahalad, *Competing for the Future* (Boston: Harvard Business School Press, 1994), pp. 90 and 217.

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