FOURTH ECONOMY | Carnegie Mellon University | NREC EXPERIENCE · EXPERTISE · EXCELLENCE

Robots in the Backyard

How the National Robotics Engineering Center changed a neighborhood, a region and an industry

An Economic Impact Study

25 Years of Economic Impact 1995–2020 ▪ Report Released December 2021

About this Report

This report was commissioned by Carnegie Mellon University. It was developed and written by Fourth Economy Consulting. It is not a traditional economic impact study, for there is simply nothing traditional about the economic impacts of the National Robotics Engineering Center. Instead, the purpose of this document is to tell the story of the economic effects that NREC has had over its 25-year history, articulate a typology through which those impacts can be cohesively analyzed, and consider what lessons might be learned from NREC's story to inform the future development of boundary-pushing institutions.

Acknowledgements

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Executive Summary

Twenty-five years ago, Carnegie Mellon University, NASA, the Commonwealth of Pennsylvania, the city of Pittsburgh and other partners came together to create a new model of academic-industry partnership. The resulting institution has dramatically changed the economy of a neighborhood, a region and an industry. This report offers an attempt to make sense of how that happened. The following executive summary contains highlights from each section of the report. For more detail please review the full report.

NREC Initial Investment: **$8–$10 Million**

Total direct funding raised by NREC: **$545 Million**
(in 2020 Dollars)

This report contains three key elements:

- a **brief history** of the development of NREC
- an **analysis of the key impacts** that the institution has had, organized into four areas of focus
- some **lessons learned** from NREC's story that would be applicable to future institutional economic development work

Alumni, Spinoffs and Partnerships

It was once assumed that the Pittsburgh region was losing too many talented college students to high-tech employment opportunities elsewhere. One of NREC's most significant contributions to the region's economy has been its vast and impressive network of alumni. They form businesses at an extremely high rate — some of which have become massive economic drivers. NREC alumni also work at many of the world's leading companies, including smaller firms and leading tech giants, like Google and Facebook. The strong network of alumni and businesses/organizations that are connected to NREC is at the heart of Pittsburgh's economic resurgence.

NREC has helped to build the robotics workforce.

64% of NREC alumni (former researchers or staff members) remained in the Pittsburgh region following their NREC employment.

(53% *still* reside and work in the Pittsburgh region.)

NREC alumni are driving the local tech sector.

3 in 5 employer firms in the robotics/AI/tech sector in Pittsburgh have direct staff ties to NREC alumni.

And they are uncommonly entrepreneurial.

20+ **active firms** founded or established by NREC alumni.

$25+ billion valuation of firms founded or established by NREC alumni.

NREC is the epicenter of *Robotics Row.*

There are over 80 companies in Pittsburgh focused on robotics, AI and related technologies. Many have located in the Strip District or Lawrenceville, and much of this development can be clearly traced to connections with NREC.

Alumni data based on social media analysis

Technology and Inventions

NREC has pioneered a novel approach to developing robotic technology and commercializing that technology through licensing and technology transition support. Its staff members are exceptionally productive in their development of intellectual property and robotics technology, its unique model for private-industry partnership makes it possible for NREC to produce technology that private industry moves closer to market-ready than most comparable institutions, and its robots have been deployed around the world, saving lives and revolutionizing operations in a variety of industries and domains.

4x rate of NREC **invention disclosures**, compared to national averages

457 technology licenses

KEY SOCIAL IMPACTS

- **Efficiency**
- **Safety & Health**
- **Environment**

GLOBAL REACH, GLOBAL IMPACT

NREC robots and technology have been deployed across companies and industries, with NREC technology officially licensed in 31 countries and NREC robots deployed on all seven continents!

TECHNOLOGY READINESS: SETTING THE CURVE

Technology Readiness Level (TRL) is measured on a scale from 1-9, moving toward commercialization. Most similar institutions operate around TRL levels 1-3, producing still-experimental technology, while NREC regularly develops applied research prototypes that are tested in a variety of environments well above TRL level 3.

Neighborhood Development

NREC's presence in Lawrenceville was not always obvious. Indeed, it still is not for many residents and visitors. But it was a major catalyst in the economic transformation of the neighborhood that has taken place in the last 25 years, which saw employment increase along with resident incomes. Real estate development has dramatically changed the physical landscape of the neighborhood, and an area that not long ago was known for post-industrial decline is now widely recognized as hip and vibrant.

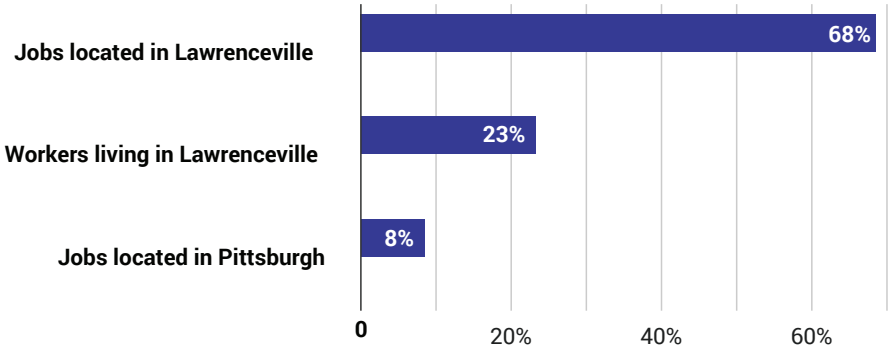
▼61%

Historic Population Decline
NREC moved into a neighborhood facing decades of population decline. More extreme than the city at large, Lawrenceville had lost over 60% of its population between 1940 and 1990.

$ x 3

Household incomes have since increased substantially.
In the last 20 years, median household income throughout Lawrenceville has more than doubled. In what were once the lowest-income areas of the neighborhood, near NREC, it has more than tripled.

Since NREC's development, job growth in Lawrenceville has dramatically exceeded the city.



Employment Change: 2002 – 2017
Data from LEHD (refers to primary jobs)

Educational Programming

NREC's impacts go far beyond its alumni network or existing technology. For 20 years, NREC staff has managed the Carnegie Mellon Robotics Academy (CMRA) and associated education programs and partnerships. Through this work, NREC has prepared tens of thousands of people for academic and professional success in the economy of tomorrow. Some programs are specifically geared toward young people, others toward adult learners. CMRA has developed partnerships to engage more diverse learners with robotics, helping to make the profession more equitable in the long term. Many of its educational programs and partners are focused in the Pittsburgh region. In this way, NREC (and CMU more broadly) is not only leading the way in innovation, it is helping to provide high-wage, in-demand opportunities for the region's workforce for years to come.

75K badges completed

250K users certified

250-350 teachers trained annually

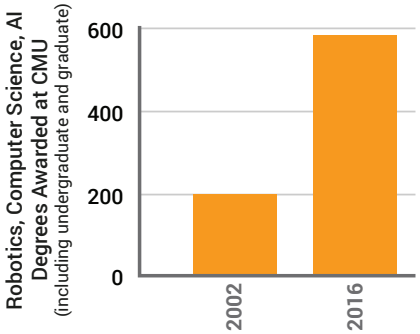
BUILDING A REGIONAL WORKFORCE

Successful programs geared toward workforce development + **Key partnerships** with local educational institutions and organizations

9%
STEM occupations projected 10-year growth vs. 5% overall

$86K
STEM median wages, vs. $38K overall

Source: BLS



Source: IPEDS, via Urban Institute

Mapping NREC's Impacts

NREC's economic impacts in Pittsburgh are as widespread as they are subtle. Stand on the 40th Street bridge and look down at the facility, and it is not at all obvious that you are looking down at a pioneering institution, the epicenter of Pittsburgh's economic transformation. But the map of Pittsburgh is decorated with connections to NREC, including companies/organizations that were created or established by NREC alumni; companies/organizations that are affiliated to NREC (through specific partnerships, alumni or technology/IP); and other businesses that partner with or are supported by NREC.

Map created by Fourth Economy with data support from InnovatePGH.

Lessons Learned

NREC's story offers a variety of lessons for economic development work at a variety of scales — especially for similar institutions that would seek to emulate its success. The following key takeaways represent an attempt to cogently distill the most important lesson that this project's analysis uncovered. And, while the story of NREC is undoubtedly an economic success in a great many ways, these lessons consider not only what went well but also what could have been done differently. For more detail on each point, please review Section VII.

1. **Engage early with local partners.**

2. **Public investments can leverage private dollars, especially in the long term.**

3. **Be patient and build the ecosystem: an institution can be both catalytic and understated.**

4. **Institutional proximity matters, but so does distance.**

5. **An active, walkable neighborhood is vital for development.**

6. **Legacy is an asset.**

7. **Be aware of unintended consequences. (Unintended does not always mean unpredictable.)**

8. **Build a sustainable business model (even if it's not a business).**

Section I. **History of NREC**

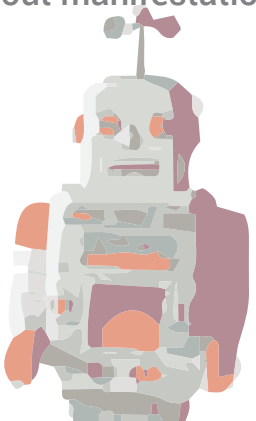
Today, the Pittsburgh region is widely associated with robotics and technology. That association is a relatively recent one, but the Steel City's evolution into a technology hub began decades ago. That story begins long before the creation of NREC, going back to the 1950s with pioneers in artificial intelligence such as Herbert Simon and Allen Newell. Simon, Newell and Alan Perlis founded the Department of Computer Science at Carnegie Mellon in 1965. These three Turing Award winners attracted a future Turing recipient, Raj Reddy, who came to CMU in 1969.

In the late 20th century, CMU was one of few universities to offer advanced education in robotics. The CMU Robotics Institute was founded in 1979, under the leadership of Dr. Raj Reddy, to conduct applied robotics and computer research, initially in partnership with Westinghouse Electric. Westinghouse supplied $3 million in seed funding and project support for technology that it then used in its facilities.

Over the successive decade, robotics research at the university expanded. The Department of Computer Science became a college within the university (the first such college in the world), the CMU Field Robotics Center was created on the main campus, and CMU became a hub of robotics talent. In 1989, CMU created the world's first Ph.D. program in robotics.

Discussions about a new model for applied research between CMU and NASA began in 1994, led by Red Whittaker and Dave Pahnos. With NASA leadership, CMU worked to establish an organization focused on commercially licensing technology that the Robotics Institute and its Field Robotics Center developed with federal funding. NASA initially invested $2.5 million in seed funding and committed additional matching funding for industry partnership projects. A Redevelopment Capital Assistance Program grant sponsored by State Senator Len Bodack Sr. and awarded by Governor Casey in December 1994 provided financial support to develop the infrastructure needed. With bipartisan political support at both state and local levels, in 1995 the city of Pittsburgh (then led by Mayor Tom Murphy), the Regional Industrial Development Corporation of Southwestern Pennsylvania (RIDC), and the Commonwealth of Pennsylvania helped the new partnership procure a site in the Lawrenceville neighborhood and funded the renovation of a historic manufacturing facility. And so the National Robotics Engineering Center (NREC) was born. What followed is the focus of this report.

> "In the early years, robotics wasn't a discipline, **it was fantasy** — lots of pundits making predictions, but without manifestation."
>
> — **Red Whittaker**, NREC founder and robotics pioneer



Pittsburgh was a very different city in the 1990s than it is today. Robotics was cutting-edge research, but hardly a well-known field of study or established economic driver, and beyond CMU's reputation within technical circles, the region was not widely associated with technology. The steel industry had recently collapsed, following a multi-decade decline after World War II. Residents had been leaving the city in droves — with net decline decreasing the city's total residential population from its 1960s' peak of over 675,000 people to fewer than 400,000 by the late 1980s.

However, it is a misrepresentation to suggest that the Pittsburgh that we know today — associated with robots and artificial intelligence, arts and cultural institutions, a robust secondary education ecosystem, vibrant neighborhoods, and so forth — is a new creature entirely distinct from that which came before. In fact, many of the city's long-standing institutions, large and small, were catalysts for the transformation that is taking place in Pittsburgh in the 21st century. Few organizations better embody that catalytic role in the region's economic resurgence than the National Robotics Engineering Center.

"We are talking about a set of technologies that companies all over the world are going to be utilizing … The opportunity for Pittsburgh is to be one of those technical centers that pushes the technology forward and, as a technical center, act as a magnet for business."

– **Dave Pahnos**, quoted in Carnegie Magazine, 1995

Pictured: The NREC facility in the early stages of demolition/renovation in 1995.

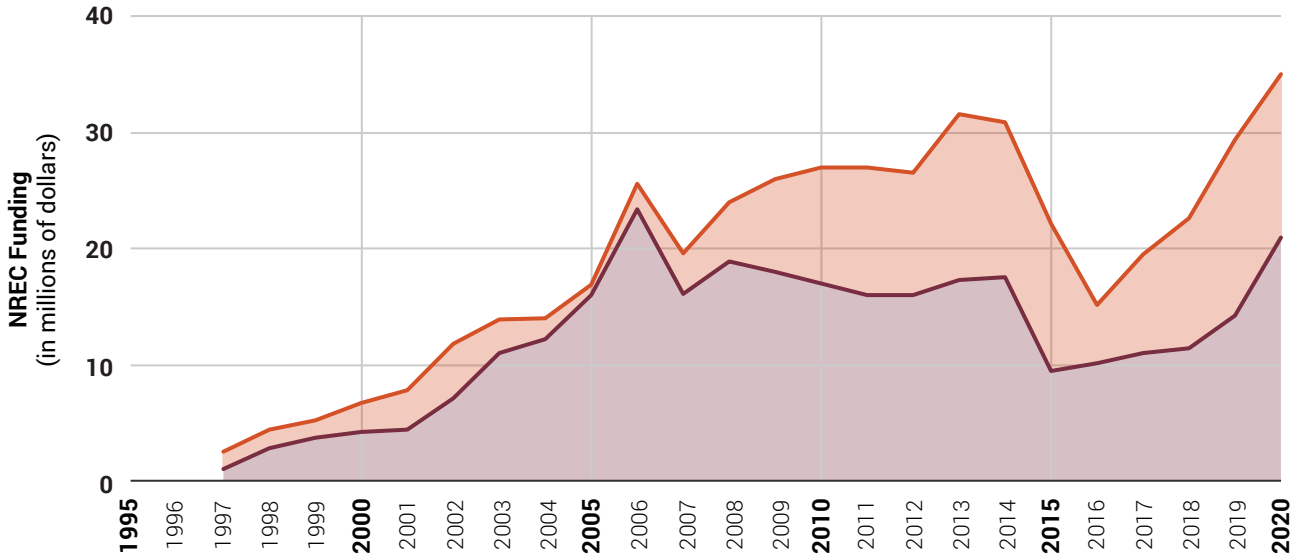
Building Rehabilitation

The story of NREC is not one of hesitance. Eager roboticists moved into trailers on NREC's site and began their work while demolition and renovation was still occurring around them. The high bays and expansive space of the new building provided a significant opportunity for growth beyond the limits of the Field Robotics Center on CMU's main campus. The new location would enable a host of NREC's future projects, many of which involved enormous machines and/or large areas of movement. For projects that required more space for testing, such as autonomous vehicles, the large outdoor space adjacent to the building provided ample room. NREC later expanded its testing and storage space, acquiring two large test sites outside of the city. But the historic foundry, with its massive size, high bays and open layout, still accommodates NREC's staff of over 160 employees and remains its main project space.

NREC Funding Over Time

NREC's funding has steadily grown over time, more or less in sync with its staffing. During NREC's initial growth period in the early 2000s, competitive public funding dominated NREC's budget. Following 2005, private industry investment expanded significantly. After the 2015 departure of numerous employees, NREC's budget declined in response to temporary reductions in capacity, but by the 2020 fiscal year, NREC reached new all-time highs for revenue and employment. In recent years, the public-private funding ratio has been between 1:1 and 3:2, with over $10 million invested annually from private companies.

NREC Annual Budget Allocation: 1997 – 2020 Private Funding Public Funding



Data from Carnegie Mellon University

NREC: Key Milestones

It is not easy to create a timeline of key milestones for NREC. The institution has yielded hundreds of significant inventions and robots over the last 25 years, and various major events and partnerships have significantly influenced its trajectory. This timeline captures *a few* of the most significant events, inventions and other milestones that stick out in the story of NREC.

2020
NREC at 25: As NREC celebrates two and a half decades of existence, its engineers and scientists continue to produce cutting-edge technology, revolutionizing a variety of industries and domains. The presence of NREC's Lawrenceville headquarters remains subtle, while the surrounding neighborhood is an almost unrecognizable transformation of its former self.

NREC
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2019
The U.S. Army selects CMU to host its AI Task Force at NREC.

2011
President Obama visits NREC to launch the National Robotics Initiative, a national initiative to accelerate the development of next-generation robots in the U.S.

2010
John Bares leaves to form Carnegie Robotics, which he locates next to NREC in Lawrenceville; Tony Stentz becomes NREC Director.

Carnegie Robotics

2015
CHIMP competes as a finalist in DARPA disaster response challenge.

1996
With support from a grant by Pa. Governor Casey's administration and local partners, NREC's headquarters building is renovated in historic mill in Lower Lawrenceville.

2006
NREC roboticists develop "Crusher" — a revolutionary autonomous ground vehicle built to improve safety for Army troops.

1999
"Roboburgh" is coined in a Wall Street Journal article.

1995
The partnership between CMU and NASA creating NREC is established.

2000
Carnegie Mellon Robotics Academy is launched.

2000
NREC expands into Department of Defense contract work.

1997
RoboCity forms.

2007
CMU Tartan Racing wins DARPA Urban Challenge; NREC contributes software engineering.

2015
Several NREC staff are instrumental in establishing Uber ATG in the Strip; Dr. Herman becomes NREC director.

Uber ATG

1995 2000 2005 2010 2015 2020

Section II. **Overview of NREC's Economic Impacts**

Key Types of Impact

The following report will be organized into sections that align with the following four key types of impacts. A basic definition for each is listed below.

Alumni, Spinoffs and Partnerships

Current and former NREC staff play outsized roles in the robotics industry both internationally and, especially, in the region. Many private companies have also benefited from partnerships with NREC. Several companies have been founded by NREC staff and alumni. Some are located in the Pittsburgh region (many proximate to NREC), and some are located elsewhere. This section explores the impacts that this robust network of alumni, partners and affiliated companies has locally and beyond.

Technology and Inventions

NREC was designed to develop a variety of potentially impactful inventions, and for 25 years, NREC-created technologies have been used in different domains of industry to make work more efficient, more productive and safer. This section explores the impacts that NREC-developed technologies have had in different industry domains and the value that NREC has created with its licensed technologies.

Neighborhood Development

Since locating its operations in Lawrenceville in 1996, NREC has had a significant (though not always obvious) effect on the surrounding neighborhood. By developing property and bringing employees and visitors to the area, it has consistently had a direct impact on nearby businesses and land value. It also attracted other businesses to develop nearby, both for logistical purposes and because of its reputation. The impacts of this development on Lawrenceville are articulated in this section.

Educational Programming

In addition to project work, NREC uses its staff and facility for educational and community purposes. The most significant of these programs is the Robotics Academy. NREC also manages other educational programs and works with local community groups to host meetings and maintain outdoor space. This section discusses how these educational and community-oriented efforts benefit the local community and prepare the next generation of robotics professionals.

The Scale of NREC's Economic Impacts

For the remainder of this report, the discussion of economic impacts will be organized by ***types of impact***, each of which may include impacts across different geographic scales. Because NREC has had such a diversity of effects, these categorical impacts help to conceptualize and organize the analysis. However, the following page includes a brief discussion of NREC's economic impacts, considered at a high level, organized by geographic scale. While more detail is included in the typological content, this may be useful for readers wishing to consider the geographic lens of NREC's impacts.

Global Economic Impacts of NREC

NREC was a unique institutional model for developing robotic technology and commercializing it through licensing and technology transition support when it was founded, and 25 years later, it remains a unique model. Less than $10 million in combined seed investment created NREC, an amount that pales in comparison to the effects that NREC-generated technology and NREC-trained staff have had throughout the global economy.

Regional Economic Impacts of NREC

Pittsburgh has now been widely associated with the robotics industry for over two decades, and the reputation is well deserved. Robotics, AI and related technologies have driven a regional economic renaissance, and NREC exists at the core of that ecosystem. The development of NREC, more than any other specific regional institution or business (excepting CMU at large), spurred the growth of businesses and attracted talent to Pittsburgh, a city that had previously followed a similar economic path to those of its Rust Belt peers. Perhaps counterintuitively, it is at the regional scale that the economic effects of NREC are easiest to spot.

Local Economic Impacts of NREC

One might assume that an institution with a global reputation, widely hailed as an epicenter of innovation and talent, would have an obvious and outsized presence in its local community, especially in the context of what was historically a working-class neighborhood facing industrial decline. But the story of NREC's role in Lawrenceville is more complex than that. It was the first, primary catalyst for the development of a technology ecosystem that has transformed the area, but it also went largely unnoticed for many years. As a world-renowned institution, it draws talent and investment in a cutting-edge industry, and opportunities remain to connect local residents and businesses with NREC and the robotics industries it catalyzed.

Section III. **Alumni, Spinoffs and Business Partnerships**

NREC has created a host of wildly cool and impressive things, but the institution's most impactful contributions to the world go beyond robots, hardware and computer code. Instead, perhaps NREC's most significant contribution is its alumni — the former staff and researchers who have gone on to found companies, commercialize new technologies and lead industries.

NREC's lauded reputation within the global robotics community is attributable to its expansive alumni network. Many alumni have founded companies and play leadership roles in both the public and private sectors, including at some of the world's leading corporations.

Many of NREC's employees and alumni came to Pittsburgh from other places, often other countries, to attend Carnegie Mellon and/or work at NREC. Some of NREC's former alumni have also left Pittsburgh to work elsewhere, but many have stayed or returned. And more than that, many have gone on to create companies based in Pittsburgh. "Robotics Row" is the now-common branding for the three-mile stretch along the Allegheny riverfront, anchored by NREC, that is home to several of these companies.

Pittsburgh Spinoffs and NREC Alumni Firms

The following are examples of Pittsburgh-based firms/organizations founded or created by NREC alumni. That is an enormous impact for a relatively small institution (with fewer than 200 employees). In 2004, CMU's Center for Economic Development found that universities create one company per every $70-$100 million of R&D. NREC alumni have created companies at five times that rate — in Pittsburgh alone — and many of those firms have become industry giants. Collectively, they are valued at over $18 billion.

Advanced Construction Robotics · Astrobotic · Aurora · Carnegie Foundry · Carnegie Robotics · Edge Case Research · IAM Robotics · Locomation · Mine Vision Systems · re2 Robotics · RedZone Robotics · thoro.ai · Titan Robotics · Uber ATG

The Epicenter of Robotics Row

In addition to firms that have directly spun out of NREC or been created by NREC alumni, many technology and robotics companies have chosen to locate near NREC. Over time, this has had a compounding effect, with a cluster of robotics companies developing as a proximate network surrounding NREC. Today, with dozens of firms in the area, it is too simple to suggest that all of these new technology-oriented companies are here simply to be near NREC, but the concentration of robotics and technology firms in what is now widely known as Robotics Row is closely tied to NREC.

Map created by Fourth Economy with data support from InnovatePGH.

Catalyst for an Innovation Hub

Technology and innovation have become driving forces in determining whether a regional economy grows or declines. The development, capture and retention of technology and innovation businesses require an ecosystem that ensures innovation can sustain long-term growth. This innovation infrastructure necessitates the presence and interplay of four key elements:

1. Robust research and development (R&D) networks generating new ideas
2. Commercialization capacity to take ideas to market
3. Investment capital that is patient and risk tolerant
4. Specialized talent that has the expertise, creativity and drive to succeed

When all of these elements work together, they form an integrated innovation ecosystem in which new ideas become businesses that scale for sustainable economic growth. A small portion of disruptive, high-growth firms will drive a significant amount of this growth. As more of these firms grow, they spin off additional firms and attract new firms that want to benefit from the collective resources and knowledge in the region.

This pattern is not unique to Pittsburgh. Other regions in the U.S. and elsewhere in the world have seen technology and innovation drive widespread economic growth, and the same four key ingredients are usually at play.

Innovation is inherently about discovery, whereas entrepreneurship is about taking risks. Dynamic regions provide the conditions for innovation and entrepreneurship to interact. This interaction is a process of learning by doing, where each research project and entrepreneurial firm serves as a training ground for the next generation of entrepreneurs, becoming a self-replicating engine of growth.

Early robotics pioneers at CMU created the nucleus for early development of an AI and robotics hub in Pittsburgh, and that provided the foundation for the success of NREC and robotics in the region. (Section III., The Impacts of NREC's Alumni and Staff, explores in more detail NREC's instrumental role in attracting, training and growing that network.)

For decades, regional leaders and planners have hailed robotics as an economic engine for the region, always expecting robotics to be the ***Next Big Thing***. Yet translating research triumphs from the laboratory to the market demanded more than smart researchers. It required the capacity to commercialize and the ability to attract investment capital. NREC's founding in 1995 provided a key catalyst for the next phase of the development of Pittsburgh as a robotics hub. NREC took robotics beyond merely being research and opened the door for entrepreneurs and companies to develop commercial applications through licensing and technology transition support. NREC's focus on developing real-world applications and the commercial license partnerships it built provided the missing ingredients in the regional ecosystem — the development of commercialization capacity, which in turn attracted patient investment capital.

Envisioning the Future

In 1999, the Wall Street Journal branded Pittsburgh "Roboburgh" and included it among the nation's 13 hottest high-tech regions. At the time, the *potential* of the robotics industry was more apparent than its success in actuality, especially from the outside. Between 1999 and 2014, when Glenn Thrush wrote about Pittsburgh's new economy and the role of robotics and artificial intelligence in *Politico**, Pittsburgh added at least 16 robotics startups: "... the rise of the robots is the storyline the city itself embraces because it represents the reassertion of Pittsburgh's irrepressible identity, its industrial DNA."

Today, there are dozens of robotics companies that were founded in or relocated to Pittsburgh, many more since 2014; many have direct links to NREC through alumni, technology/IP or business partnerships. At least 20 were founded or established by NREC alumni.

* The Robots That Saved Pittsburgh

As NREC reaches its 25th anniversary, its mark on the local (and global) robotics industry is undeniable. The pace of technology development and startup formation has accelerated dramatically over that time. As RIDC's Don Smith observed, "(NREC) has not been an overnight sensation." In addition to the pioneering research and talent at CMU and NREC, it has taken time, patience and many partners to realize the impact we see today. When you look at NREC today, it exemplifies the story that everyone wants to tell about innovation-based development. A seed investment from NASA 25 years ago helped foster core expertise and technologies that led to relationships with commercial companies that put products on the market through licensing and technology transition support. It generated spinoffs and attracted companies and more downstream partners to Pittsburgh. The region is now one of the key movers in autonomous vehicles, having captured advantages when there were no industry leaders — nor really a robotics industry at all. Without a master plan, the development of this industry played out through a series of intentional decisions about what technology challenges to attack, making critical pivots between government and commercial work.

Photo: Guests on a tour of NREC's facility sample virtual reality software.

NREC Alumni: Driving Pittsburgh's Economic Turnaround

Whether or not it was true in 2000 that the majority of CMU's robotics graduates left Pittsburgh, it is certainly not true anymore. Today NREC is a major driver of regional economic growth, largely because its alumni often remain in Pittsburgh, found local companies and play leadership roles in the region's economy.

To better understand the reach of NREC's current and former staff, Fourth Economy used social media data on 295 NREC staff and alumni to map their paths from their educational alma maters to NREC and then on to other companies. Out of 196 NREC alumni identified using their profiles, 126 (64%) remained in the Pittsburgh region following their NREC employment, and 104 (53%) currently reside and work in the Pittsburgh region. (Some initially left and later returned to the region.) This is an impressive rate of regional retention for an industry that is highly in demand and has an extremely mobile workforce.

In total, these alumni work for 120 different companies, 48 of which are in the Pittsburgh region. The strongest local connections are at Uber Advanced Technologies Group (ATG), Argo, Carnegie Robotics, Titan Robotics, Mine Vision Systems, IAM Robotics, Edge Case Research, Locomation, Aurora, Advanced Construction Robotics and Carnegie Foundry. Nine of those 10 firms were founded by NREC alumni. The 10th, Uber ATG, was established in Pittsburgh with dozens of NREC alumni and led by NREC's former director.

20 years ago...

"More than 80 percent of CMU's robotics graduates leave the region for robotics-related jobs elsewhere."

— Pittsburgh Post-Gazette article, February 13, 2000

While it is unclear how much stock to put in the above claim from 2000, the majority of NREC's alumni for whom recent data is available now remain in the region.

Robotics remains a relatively small industry, but with approximately 3,000 employees in robotics, artificial intelligence and related technology companies in the city of Pittsburgh, these represent a significant share of the city's jobs in manufacturing (6,300) and information technology (6,600), the two industries most closely identified with robotics. It is also, unsurprisingly, a growing industry with many high-wage occupations.

Of the 81 robotics companies identified in Pittsburgh, analysis of NREC's alumni uncovered that at least 59% have direct staff ties to NREC. (Others likely have links that were missed.) That is an impressive level of dispersion for an institute whose direct employment, which has never exceeded 200 people, now makes up only a small part of the region's industry — and this, in a sector that has only recently seen substantial growth. In addition, the fact that more than 20 of those firms were founded by NREC alumni is phenomenal.

NREC Alumni Leading Autonomous Vehicle Development

Robotics is a diverse field with many more nuanced specialties. The development of autonomous driving systems is one area of research that has received an enormous amount of attention and investment, particularly in the last five years. Much of the cutting-edge research and talent that has given rise to the autonomous vehicle industry can be traced directly to NREC and its alumni, and it is no surprise that Pittsburgh has become the go-to hub for the development and testing of autonomous vehicles.

Dr. Chris Urmson, the technical lead of Tartan Racing, went to Google to lead the Google autonomous car project that became Waymo, along with other alumni from NREC. Together with another NREC alumnus, Dr. Drew Bagnell, he later founded Aurora, another autonomous driving company located a few blocks northeast of NREC in Lawrenceville. Dr. Raj Rajkumar, a CMU scientist on the Tartan Racing team that worked with NREC staff, started Ottomatika, Inc., a company focused on self-driving technology that was recently acquired by Aptiv (then Delphi), another autonomous driving company whose staff includes NREC alumni. Aptiv recently moved hundreds of employees into a new office as part of the Hazelwood Green development in Pittsburgh. In 2015, several staff members from NREC, including then-director Tony Stentz, moved to Uber Advanced Technologies Group (ATG) — which had been previously established under the leadership of former NREC director John Bares. Some NREC engineers who moved to Uber have since gone to other autonomous vehicle companies in the region. Bryan Salesky, an NREC alumnus and one of the scientists who moved to Google with Urmson, co-founded Argo AI along with Dr. Peter Rander, another NREC alumnus, in 2016.

In 2019, Carnegie Mellon University and Argo AI announced a five-year, $15 million sponsored research partnership to fund research into autonomous vehicle technology — the Carnegie Mellon University Argo AI Center for Autonomous Vehicle Research.

Entrepreneurship at NREC

Since its founding, NREC has been a hub of entrepreneurship. Founder Red Whittaker embodied this. (He had started a private company, Redzone Robotics, even before opening NREC.) Since the beginning, the same expertise required to develop, license and transition cutting-edge robotics technology to commercial and public applications lent itself to the creation of private companies and spinoffs. In fact, there are several examples of private spinoffs that were created by NREC staff and alumni to commercialize, advance or service NREC-developed technology simply because other companies lacked the expertise.

NREC's leadership has always embraced these entrepreneurial offshoots, working closely with alumni-affiliated firms to continue advancing the technology made possible by NREC. The physical environment of NREC was also an asset to entrepreneurial outgrowth, for the building could accommodate (and indeed often has) space for private companies and other partners working in collaboration with NREC.

Perhaps the most significant example of an entrepreneurial offshoot of NREC came in 2010, with the creation of Carnegie Robotics by John Bares, which originally leased space within the NREC facility. Carnegie Robotics later went on to create its own sizeable facility in another renovated steel facility, the former Heppenstall building, located adjacent to NREC in Lawrenceville.

Global Talent Reach

It is obvious, based on qualitative evidence, that NREC is a well-respected institution with a global reputation for excellence in the world of robotics, AI and technology, but its prestige is reinforced by its alumni network. Its former employees are scattered across a "who's who" list of major technology companies. Scanning its alumni connections, one might get the impression that NREC employs a lot more people than it actually does, or that it has particularly high rates of turnover or short-term staff engagements, which it generally does not. Instead, experience at NREC is a significant indicator of an alum's capability in technology and robotics, and those who leave NREC are competitively positioned for the most desirable jobs in the industry. Among former employees for whom social media data is available, 8% worked for Google, Apple, Facebook or Amazon.

Nationally, NREC alumni work in companies across 24 major cities, with strong nodes in San Francisco, Seattle, Washington, D.C., Boston and New York. NREC alumni work at 28 companies in the Bay Area alone. NREC's reach also extends internationally, with former employees working in Germany, the U.K. and South Africa. In addition to NREC's global influence, its alumni are leaders in their companies; 13.6% of NREC's former and current employees have gone on to become C-suite executives.

In addition to private-sector partnerships and spinoffs, NREC continues to create exciting, new public partnerships. In 2019, CMU was selected to host the U.S. Army's Artificial Intelligence (AI) Task Force, to be housed at NREC. The initial contract provided a funding vehicle for up to $70 million over five years. The Task Force's choice to locate in Pittsburgh and at NREC was driven by NREC's legacy of not only cutting-edge innovation, but also strong collaboration, a legacy to which this partnership now adds.

Section IV.

Technology and Inventions

Innovation rarely follows a straight path from idea to impact. Innovation is about much more than invention — it is about the ability to apply inventions in the real world. Traditionally, academic research in the United States tends to produce a lot of knowledge and a variety of ideas for inventions. NREC pioneered a different approach.

Technology Transfer at NREC

Twenty-five years ago, NREC was established to do something new in the nascent world of applied robotics research. Although the NREC model has proven successful, from the perspective of both the associated companies and host university, and has a stellar reputation within the robotics industry, as the industry has developed NREC has remained a unique model for developing robotic technology and commercializing it through licensing and technology transition support.

The research and development process for applied technology is best understood through the framework of Technology Readiness Levels (TRL), a conceptual framework developed by NREC's earliest partner organization, NASA, during the Apollo program. Originally, the framework measured the space-readiness of a technology. Today, it is more commonly applied to commercial technology products.

The scale (see diagram) ranges from 1 to 9 in ascending order of the maturity of a technology. Technology that has reached level 9 is fully operational and ready to be deployed at scale for commercial purposes. Most robotics, AI and other applied technology research institutions deal with lower levels of technology readiness — technologies that are not nearly ready for commercial deployment. NREC is uncommon in two ways. NREC covers a particularly wide range of technology readiness, encompassing both relatively novel ideas and close to commercial-ready technologies. NREC also regularly advances applied research prototypes that are tested in a variety of environments well above level 3 of the TRL spectrum — close to commercially deployable applications — which is far beyond the norm for academic research institutions.

Technology Readiness Level (TRL) Diagram

TRL 1 — basic principles observed
TRL 2 — technology concept formulated
TRL 3 — experimental proof of concept
TRL 4 — technology validated in laboratory
TRL 5 — technology validated in relevant environment
TRL 6 — technology demonstrated in relevant environment
TRL 7 — system prototype demonstration in operational environment
TRL 8 — system complete and qualified
TRL 9 — actual system proven in operational environment

NREC's applied research prototypes are tested in a variety of environments well above TRL Level 3.

Diagram note: These specific definitions are taken from the EU's Horizon 2020 TRL framework, which is commonly cited for its TRL language, but the general definition of each level is consistent across most other industries and networks.

Invention by the Numbers

NREC is not only exceptional for the broad scope of types and levels of technology that its roboticists and engineers work with, it is also prolific in the volume of its work. This is evident from technology development and disclosure data. The choice of whether to pursue a patent or other intellectual property protection is driven by a variety of factors. NREC only pursues patents for a portion of its inventions, but patents combined with other measures of intellectual property provide insight into the reach and practical applicability of NREC's work.

NREC has filed 846 unique invention disclosures — 93% of which were pursued or further developed. If NREC had performed as well as the average U.S. university, it would have generated only 203 invention disclosures based on the amount of R&D. That NREC has produced 4X as many ideas as would be expected is a testament to the productivity and talent of NREC researchers.

4x

the rate of **invention disclosures**, compared to national averages

In recent years, NREC has been particularly active with respect to intellectual property filings. Fully 72% of these invention disclosures have occurred in the last five years (much of this is attributable to autonomous vehicle development and related technology, with activity in that space surging dramatically in the 2010s).

Generating ideas is an important part of technological innovation, but what really matters is whether these ideas are useful. Again, the numbers tell only part of the story.

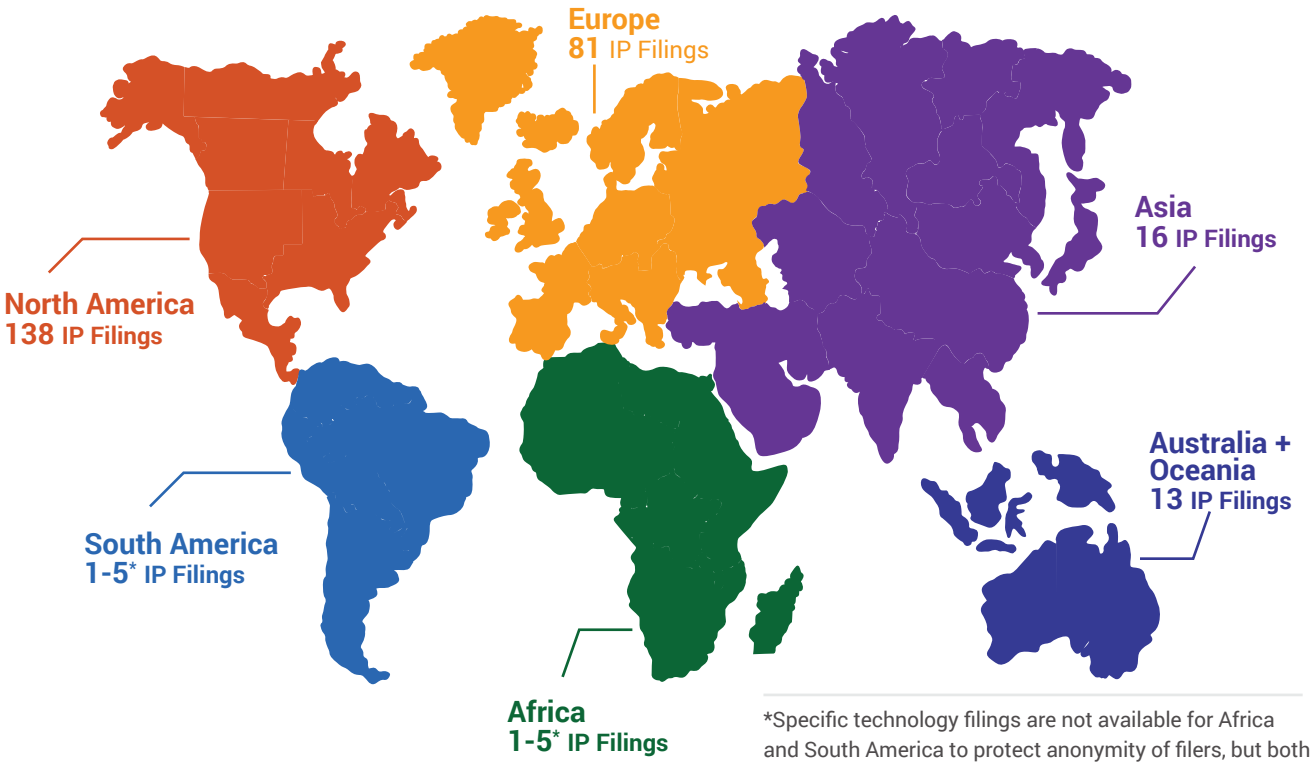
NREC has been awarded 121 patents, a number that certainly needs more context. **NREC's patents are *2X higher* than what would be expected for the average U.S. university based on its amount of R&D investment**. The average U.S. university would have produced only 59 patents. NREC, through Carnegie Mellon University, has licensed 457 technologies to 38 unique companies.

457 technologies

Taken together, these numbers offer a clear finding: NREC not only generates a lot of ideas, it generates a lot of useful ideas. Those ideas are being brought to the market by dozens of private companies. Most of NREC's technologies are commercialized through licenses; technologies are also brought to market through other partnerships. In total, NREC has developed technologies with 42 local, national and international corporations. This list includes major global corporations as well as household names and hometown favorites. (But many of the smaller Pittsburgh-based companies represent the top-tier firms in their specific industry.) In constant 2020 dollars, NREC has received more than $25 million in license and royalty revenues from an estimated $800 million in sales over the preceding 25 years. Due to the confidential nature of much of NREC's work, company- and location-specific data cannot be published, but some examples are profiled in the following subsection, Technology Profiles.

Geographic Reach of NREC Technology

In addition to having impacts across companies and industries, intellectual property and inventions developed at NREC also have impressive geographic reach. NREC robots have been actively deployed on all seven continents (including Antarctica!), and intellectual property filings from NREC are specifically assigned in 31 different countries across the world.



*Specific technology filings are not available for Africa and South America to protect anonymity of filers, but both continents have between 1 and 5 licenses registered.

Social Impacts of NREC Technology

While NREC's robots are extremely diverse in their applications and purposes, they have generally yielded three key types of impacts on society:

- Environmental
- Health & Safety
- Efficiency

Technology Profiles

Technologies pioneered at NREC have produced business efficiencies, reshaped industries, improved the health and safety of workers, and pushed the bounds of exploration on Earth and in space. In the mining industry, NREC robots have improved productivity and worker safety, and introduced technology into work processes to limit waste and machine downtime. NREC robots have also increased agricultural yields while meeting strict quality standards. NREC robots deployed in the energy industry have carried out on-site inspections in hazardous environments, and within defense NREC robots have pioneered autonomous vehicle technology and have saved lives through the detection of anti-personnel mines. In health care settings, NREC robots have teamed with pharmaceutical companies to find drug treatments for neuropsychiatric and neurodegenerative disorders. And in outer space, NREC technologies used in Mars rovers inspired the public and a generation of new scientists and engineers. The profiles on the following pages represent only a few examples of robotic applications in each industry.

AGRICULTURE

Grain Quality and Active Fill Control

2001–2015 | Deere & Company

Grain Quality for combine harvesters uses sensing to adapt to changing conditions and crops to give consistent grain quality. **Both products minimize waste from the harvesters and therefore generate more food per acre of farmland.** Active Fill Control is an automation product simplifying the unloading process in John Deere's forage harvesters. Active Fill Control uses stereo remote sensing and image processing to detect the fill of the trailer and direct the fill spout toward open empty spots.

* Caterpillar Inc.

MINING INDUSTRY

Autonomous Haulage System

2008–2015 | Caterpillar Inc.

Developed in conjunction with Caterpillar, the Autonomous Haulage System is a system for automating large off-highway trucks in mining operations. The system **navigates without human interaction and reduces the chances for injury by limiting the number of people working around heavy equipment.** Sophisticated perception technologies allow the trucks to "work safely with and around other mine equipment and personnel, even in congested areas."* The system also reduces costs by enhancing equipment availability and overall productivity. Caterpillar has deployed more than 275 autonomous trucks with this system.

ENERGY

Sensabot

2010–2015 | Shell Global

Sensabot is a remotely operated mobile robot that inspects and monitors industrial facilities. It is designed to carry out on-site inspections in hazardous environments like oil and gas fields and facilities, brownfields and sour fields. Sensabot **removes personnel from direct exposure to the facility by remotely carrying out essential inspection tasks, which significantly lowers individual risk.**

DEFENSE

Laser Coating Removal System

2010–2016 | U.S. Air Force

The Advanced Robotic Laser Coating Removal System is used to remove coatings from U.S. Air Force aircraft. The system uses a powerful laser stripping tool and complex robots to automatically remove paint and coatings from aircraft. In addition to making an otherwise-tedious process quicker, the system **reduces pollution normally caused by coating removal.** NREC staff spun off the company Titan Robotics to support the systems and commercialize the technology.

OTHER INDUSTRIES | PHARMACEUTICAL

Drug Discovery

2001–2007 | PsychoGenics, Inc.

In the process of drug discovery, biotechnology/ pharmaceutical companies evaluate chemical compounds to find candidates for new drugs. For drugs that treat neuropsychiatric and neurodegenerative disorders, drug discovery involves observing and documenting the behavior of test subjects. The drug discovery system created by NREC for PsychoGenics, Inc. monitors the behaviors of mice through a computer imaging system. **Using machine learning, the system detects the effects of chemical compounds, advancing potential treatments for various disorders**. Tens of thousands of compounds have been screened so far, with promising new therapies identified for further research and development.

OTHER INDUSTRIES | DEMINING

Land Mine Detection System

2006–Present

NREC has developed several iterations of demining robots. Unmanned demining systems use robots as a mobile platform to carry the required tools for detecting and locating antipersonnel mines. NREC's demining robots have been **deployed in both humanitarian applications and to protect military personnel in combat areas, saving countless lives.**

OTHER INDUSTRIES | SPACE EXPLORATION

Mars Opportunity and Curiosity Rovers

2004–2011

Designed for a 90-day mission and expected to travel the length of 10 football fields, Mars Opportunity Rover's mission in fact lasted nearly 15 years, with the rover traveling more than 28 miles on the Martian surface. In total, Opportunity took more than 217,000 images and found hematite, a mineral that forms in water, at its landing site.* The Curiosity rover followed, landing on Mars in 2012, and has continued surface operations for more than nine years. In that time, Curiosity has taken more than 700,000 images and continues to collect, grind, distribute and analyze samples of soil and rock.

Carnegie Mellon University engineers and graduate students led by Tony Stentz provided critical algorithms and software for the autonomous navigation software for the rovers. A news release details the technology: "The high-level planning performed by the autonomous navigation software is based on a program called Field D*, which was created by Tony Stentz, director of CMU's National Robotics Engineering Center, and his former student, Dave Ferguson, under sponsorship of the Army Research Laboratory. **The software builds a large-scale map of the terrain a robot encounters, helping it not only evaluate paths forward, but providing a memory so that it can retrace its steps or plot a new path if it encounters a cul-de-sac or some other obstacle.**"

The Mars rovers inspired the public and a generation of young scientists and engineers who became space explorers with the missions. The technical legacy of the rovers, made possible by the work of NREC and the Robotics Institute, will continue to drive new advances in future space missions.

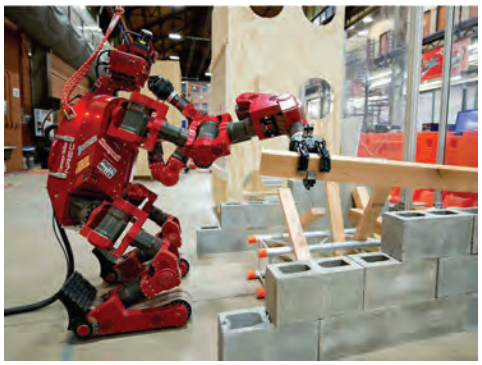
* According to NASA. Feb 13, 2019 Press Release.

OTHER INDUSTRIES | AUTONOMOUS VEHICLES

DARPA Urban Challenge

2007 | General Motors

The 2007 DARPA Urban Challenge involved a 60-mile course completed by 11 teams fielding fully autonomous vehicles. Rules included obeying all traffic regulations while negotiating with other traffic and obstacles and merging into traffic. Led by Red Whittaker of the Robotics Institute, the Tartan Racing team, a collaborative effort by Carnegie Mellon University and General Motors Corporation, won the event with their vehicle "Boss," a heavily modified Chevrolet Tahoe. **NREC provided the software engineering support to make sure the system would be robust enough to operate for the entire race.**



OTHER INDUSTRIES | DISASTER RESPONSE

CHIMP

2013–2015

CHIMP was created for the DARPA Robotics Challenge, designed in response to the Fukushima nuclear accident. **The robot can assist in disaster response in areas that are too dangerous for humans to work.** CHIMP can open doors, turn valves, connect hoses, use hand tools, drive vehicles, clear debris and climb stairs. These tasks are relatively easy for humans, but very difficult for robots. Performing them required technical advances in perception, supervised autonomy, decision-making, mobility, dexterity, strength and endurance.

OTHER INDUSTRIES | CIVIL ENGINEERING

Mississippi River Mat Sinking

2017 | SIA Solutions

NREC partnered with the U.S. Army Corps of Engineers to modernize mat sinking operations on the Mississippi River, a vital commercial waterway that drains 41% of the nation's water. NREC's mat sinking robot, ARMOR 1, will be the largest it has ever produced, and will **automate the mat assembly and launching process, preventing riverbank erosion throughout the rivershed.** Other benefits that will be derived from ARMOR 1 will be an overall increase in worker safety while lowering operating costs.

Section V.

Neighborhood Development

How NREC Changed Lawrenceville

Today, "Robotics Row" is a commonly used designation for an area that spans the Strip District and Lawrenceville neighborhoods in Pittsburgh, associated with the many technology companies and related organizations that call it home. In 1995, however, when initial plans for NREC were taking shape and the location of the site was being determined, no such name existed, for no such businesses existed. Lawrenceville* was a traditional working-class Pittsburgh neighborhood, with dense row houses, a few staple neighborhood businesses, several still-active factories and other manufacturing businesses, and many vacant industrial buildings. That it would, in a few decades, transform into an area synonymous with cutting-edge technology and a vibrant cultural scene would surely have seemed unlikely to most who lived in the area.

The establishment of NREC in a 100-year-old steel foundry on 40th Street was the first major move in that transformation. And while the creation of NREC's facility did not dramatically change the look or perception of the neighborhood, it formed the primary root — the sturdy and persistent source of growth for an economic ecosystem that is only now reaching maturity as a regional industry. The hope at that time was that locating NREC in Lawrenceville would help revitalize a distressed, mostly forgotten area with a concrete factory and some abandoned warehouses. Mulugetta Birru, the executive director of the Urban Redevelopment Authority at the time, expected that the facility would start to change the image of Lawrenceville. It became Pittsburgh's new frontier. The choice of the site in Lawrenceville started a clustering effect that positioned the community in a unique way. Lawrenceville's original business district developed largely because of the industrial employment base in the neighborhood. The arrival of NREC, its partners and spinoff companies energized and shaped the redevelopment of the business district.

After the development of NREC, the Regional Industrial Development Corporation of Southwestern Pennsylvania (RIDC) began to actively acquire and redevelop property in Lawrenceville and the Strip District. This occurred long before a booming real estate market was present. At that time, RIDC wasn't outbidding anyone for property in Lawrenceville because there weren't any other bidders. But early glimpses of a vision for Lawrenceville's future as a technology hub and as a scenic area with a developed riverfront began to form, and NREC was central to that narrative. According to Don Smith, president of RIDC, leveraging NREC has long been RIDC's critical strategy for recruitment and development in the area.

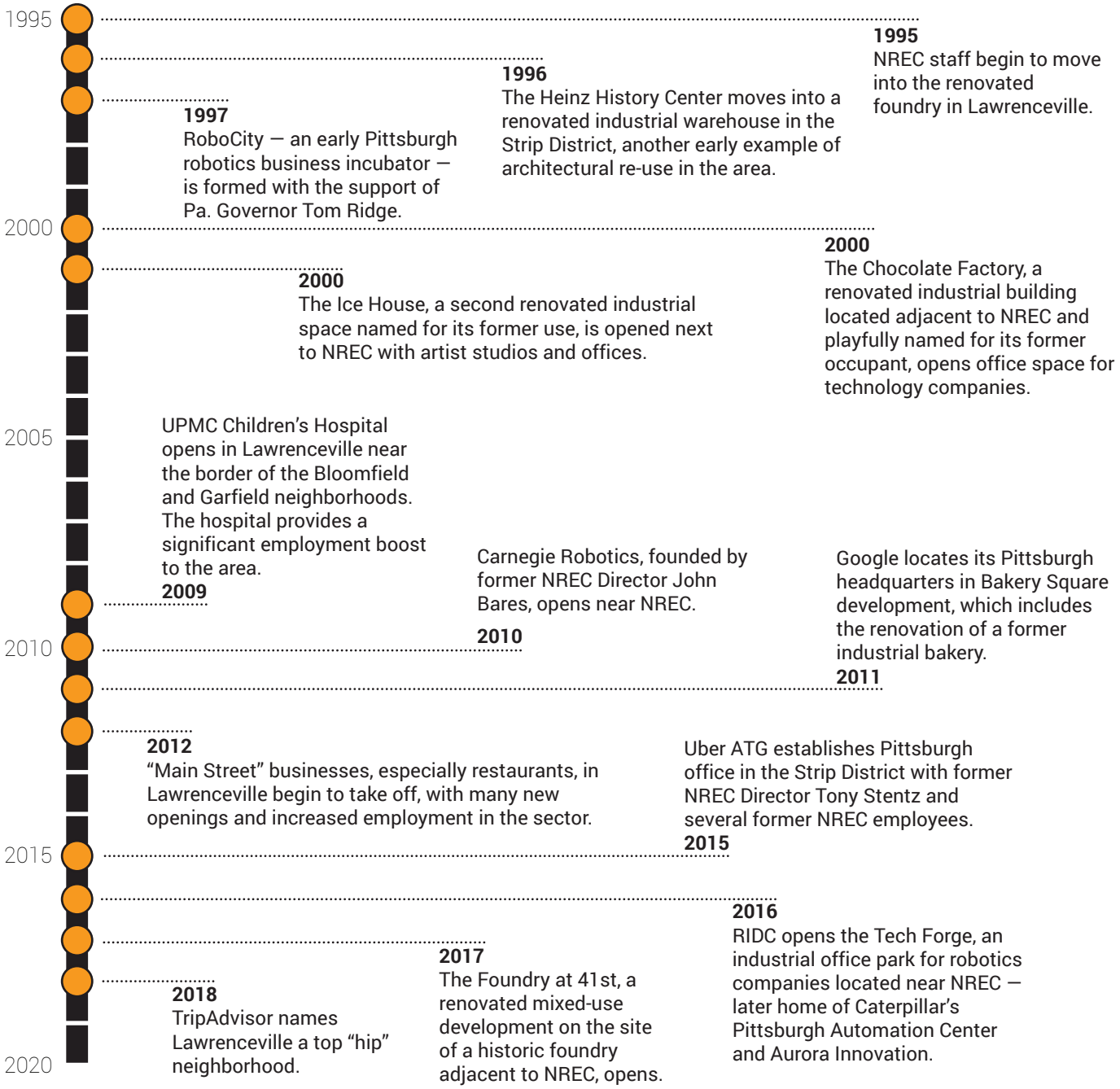
*Technically, Lawrenceville consists of three separate neighborhoods: Lower Lawrenceville, Central Lawrenceville and Upper Lawrenceville. Throughout this report, unless otherwise specified, "Lawrenceville" refers to the combined area and population of all three.

"The Lawrenceville-based firm designs virtual reality software to automate vehicles, animate movies and television programs and create three-dimensional interactive sites on the World Wide Web."

This 1997 description of Simation, Inc. — the first RoboCity-affiliated spinoff firm (no longer active) — from the Pittsburgh Business Times sounds quaint in its description of 3D internet graphics, but overall it still captures the cutting-edge nature of AI and robotics technology.

Real Estate Development in the Area

NREC's redevelopment of the historical foundry in Lawrenceville proved to be a great move on the part of the institution. The building space and location made NREC's work possible. Even more significant was the positive spillover it had on industrial real estate in the surrounding area. The Strip District and Lawrenceville, historically industrial areas on the south bank of the Allegheny River, were (and still to some extent are) filled with vacant and underutilized warehouses, factories and industrial buildings. But today, many of those buildings have been filled with robotics companies and other advanced manufacturing companies. Others have been renovated as offices, condos and apartments. Just in the immediate vicinity of NREC, five other buildings that were historically used for manufacturing have been redeveloped for new uses.

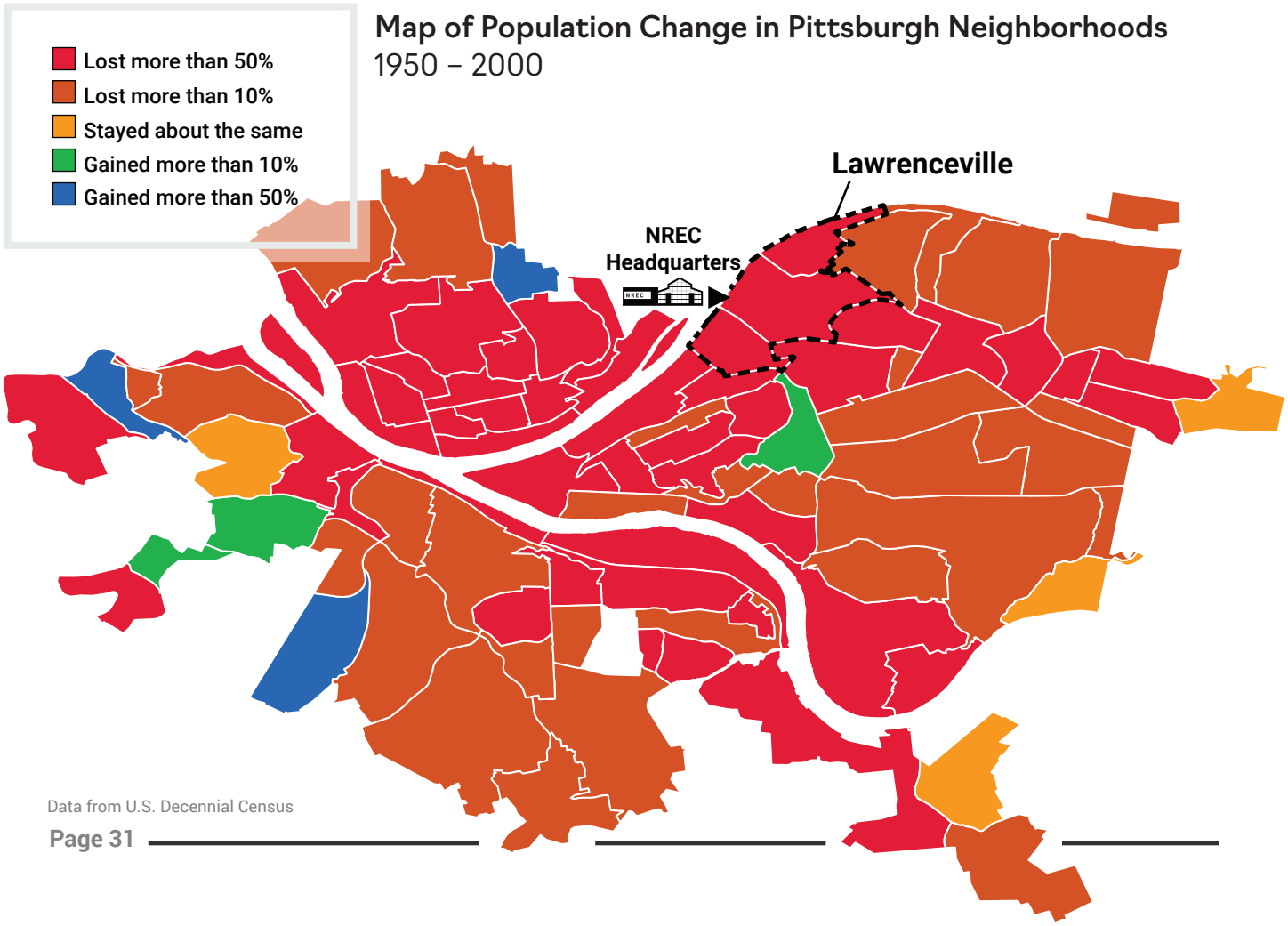


The Changing Face of Lawrenceville

Lawrenceville's population, which had been declining for decades, has only recently shown signs of improvement. The decline in Lawrenceville predated but has largely mirrored the decline in the city. The most recent estimates, collected between 2014 and 2018, show a small gain over 2010 levels, although the total population is still a fraction of the peak population for the area. From 1950 to 2000, Lawrenceville lost more than 50% of its population. That pattern only changed recently; at the end of the 20th century its population was still significantly declining, dropping 11% between 1990 and 2000. The decline continued in the first part of the 21st century, with losses of 10% from 2000 to 2010. The recent (2014–2018) estimates record the only period of growth in Lawrenceville's population since at least 1940.

	1950	1960	1970	1980	1990	2000	2010	2018
Lawrenceville population	26,657	20,810	17,061	13,875	11,845	10,590	9,492	9,598
Lawrenceville change	-3,375	-5,847	-3,749	-3,186	-2,030	-1,255	-1,098	106
Lawrenceville % change	-11%	-22%	-18%	-19%	-15%	-11%	-10%	1%
Pittsburgh % change	1%	-9%	-15%	-18%	-13%	-10%	-8%	-1%

Map of Population Change in Pittsburgh Neighborhoods
1950 – 2000



Data from U.S. Decennial Census

Demographic Changes

Obscured by the muted population numbers, Lawrenceville *has* experienced a flurry of building activity in recent years. It is probable that there has also been a more significant increase in population that is not yet captured in available estimates, but either way, this recent development has shifted the balance of the housing market in Lawrenceville. As of 2000, 48% of all households rented, but by the five-year period between 2014 and 2018 that number had increased to 55%. The conversion of owner households to rental units has pushed Lawrenceville to the forefront of the rental boom that has happened in Pittsburgh. New construction in the most recent decade has produced a number of both new owner and renter units in the neighborhood. These changes in the housing market set the stage for changes in the demographics of the neighborhood.

With that shift has come changes in the makeup of the population. Lawrenceville's demographics are trending younger. In the five years between 2014 and 2018, the median age of the neighborhood dropped from 38 to 34 years old, as more young professionals moved to the neighborhood. This change in demographics brings Lawrenceville more in line with the city of Pittsburgh as a whole, whose median age stayed level at 33 years old between 2014 and 2018. (But it is worth noting that the city's median age is driven down significantly by the large university student populations — relatively few of whom, especially younger undergraduate students, live in Lawrenceville.)

Racial demographics show that Lawrenceville, which was historically a mostly white neighborhood, remains predominantly white. The most recent estimates indicate that more than five out of every six Lawrenceville residents are white. The brief shift toward more non-white residents from 2000 to 2010 reversed itself in 2014–2018 estimates. It is unclear what accounts for this change, with the Black population increasing sharply and then decreasing sharply within the span of less than two decades. It is also worth noting that those more recent estimates, from the American Community Survey, come with a significant margin of error for small areas, such as the four census tracts that make up Lawrenceville.

Table: **Race in Lawrenceville over time**

	2000	2010	2018 estimates
White	86%	77%	87%
Black	11%	18%	9%
Asian	2%	1%	2%
Two or more races	2%	2%	2%

Table: **Age in Lawrenceville over time**

	2000	2010	2018 estimates
Under 18	18%	16%	10%
18-34 years	21%	32%	43%
35-64 years	36%	36%	33%
65 and older	24%	16%	14%

All data come from the U.S. Decennial Census and 2014–2018 five-year American Community Survey Estimates, analyzed by tract.

Household Income

Since 2000, household incomes in Lawrenceville have risen. In 2000, all census tracts within Lawrenceville had lower median household incomes than the city of Pittsburgh at large ($28,588 in nominal dollars), meaning that, more often than not, even households in the highest-earning sections of the neighborhood likely earned less than those across other parts of the city. Lower Lawrenceville contained the lowest-income areas within the neighborhood, and Upper Lawrenceville contained the highest-income areas. By 2014–18, all census tracts that make up the neighborhood had significantly higher median household incomes than the city ($45,831 in nominal 2018 dollars), and the income patterns within the neighborhood had reversed: Lower Lawrenceville and part of Central Lawrenceville now contained the highest-income areas within the neighborhood.

In other words, since 2000, household incomes in Lawrenceville have increased at a much faster rate than households across the city. Median household income in Pittsburgh grew by 60%, considerably faster than the U.S. at large over the same period. And while precise estimates are not available at a combined neighborhood geography, it is clear that during that same period, **household incomes more than doubled in Lawrenceville**. Furthermore, in what were previously the lowest-income areas of the neighborhood (southeast and southwest of NREC), median household incomes tripled.

It would be unreasonable to suggest that this was simply the effect of NREC, just as it would be impossible to tease out specifically what portion of these changes is directly attributable to its presence. But it is fair to assume the economic transformation in the neighborhood was spurred largely by the market for technology-oriented development proximate to the facility.

Before NREC, Lawrenceville was older, lower income and mostly white. To whatever degree the arrival of NREC restored market interest in Lawrenceville (clearly NREC played a sizable role in that change), those development forces have led to a community that is younger, wealthier and still mostly white. NREC had no direct role in the redevelopment of the housing market, and in fact, it had little direct role in any of the real estate development in the community beyond its own facility. However, it is important to understand the unintended consequences that a catalytic development can have. The experience of NREC in Lawrenceville may provide critical lessons for future development, which we explore briefly in the final section of this report, *Lessons Learned*.

Pictured: NREC's future home and surrounding neighborhood, seen from across the river, 1995

Development and Gentrification

Over the last century, Pittsburgh has been the site of dramatic physical and social changes. Where Pittsburghers live and the work that they do has shifted several times, and although these patterns affected Lawrenceville, the neighborhood did not exactly conform to the city's broader residential and employment trends.

In the 1960s, for example, the lower Hill District was the site of the massive displacement of a flourishing African American neighborhood. Exclusionary development and housing policy led to economic decline in other population centers in the city, such as the East Liberty neighborhood. The further collapse of the steel industry in the 1980s represented a nadir for the area's economy. But the post-industrial economic renaissance that followed came with substantial negative consequences, especially for Black Pittsburghers.

Lawrenceville offers a different example of gentrification and displacement than some other areas of the city. Historically a European immigrant, working-class neighborhood, the compounding effects of racial segregation that often drive gentrification were less of a factor in Lawrenceville's history. However, predominantly white neighborhoods in highly racially segregated cities like Pittsburgh have almost always practiced both de facto and de jure methods of segregation against people of color.* And the same result — racially exclusive patterns of development — is now primarily achieved through market forces.

NREC, as one of the primary catalysts for the seismic shift in Lawrenceville (and the neighboring Strip District), has had mostly positive direct economic effects, but it has also created market demand for both commercial and residential real estate that may have unintendedly priced out renters and businesses. And while some of these negative impacts could have been mitigated by better planning on the part of public institutions and private industry, it is important to emphasize that the concerns that exist today were not apparent at the beginning this process. Gentrification was neither a common term nor, even in concept, a widespread concern in the area.

Lawrenceville's decline was slow, and not triggered by specific events in the same way as other neighborhood centers in the city. This influenced both the physical and cultural context of the community in the early 1990s, when NREC first came to the neighborhood. By that point, the decline in Lawrenceville was manifest and obvious and NREC's establishment predated most of the now commonly appreciated indicators of Pittsburgh's economic renaissance. With neither the city nor the neighborhood experiencing any growth, the timing of NREC's founding likely influenced residents' lack of awareness of their new neighbor. For many years, NREC's presence went largely unnoticed — and for residents who may have noticed, the robotics facility neither seemed to herald the neighborhood's revival nor threaten its gentrification.

* Lawrenceville and the Strip District actually were redlined in Home Owners' Loan Corporation (HOLC) maps published in 1937, meaning that they were deemed the most hazardous type of area in which to invest in housing. But, unlike many other areas, which were marked hazardous explicitly because they were home to a concentrated African American population (hence the racial association with the term today), HOLC deemed Lawrenceville and the Strip hazardous primarily because of their low-value buildings (many of which had been damaged in recent floods), mix of European immigrants and declining economic conditions (with mills in the areas closing in the early 20th century).

Jobs in Lawrenceville

Investments in the Lawrenceville neighborhood, especially NREC and related technology businesses, and the UPMC Children's Hospital, have substantially increased local economic activity. Neighborhood-level employment data reflects gains in total employment, high-paying primary jobs, and jobs in high-growth industries. Since 2002, the earliest date for which neighborhood-level job numbers are available, both the number of jobs in the Lawrenceville neighborhood and the number of jobs held by Lawrenceville residents have increased dramatically.

From 2002 to 2017, the number of total jobs held in Lawrenceville increased by 71%, from 5,251 to 8,967. By 2017, 95% of jobs in Lawrenceville were primary jobs (meaning that they were either the employee's only job or the job at which the employee worked the most hours if the employee also held other jobs). Development that is driven by low-wage, part-time job growth would likely generate lower rates of primary employment. Jobs in Lawrenceville are also increasingly high-paying. From 2002 to 2017, Lawrenceville added 2,950 jobs with incomes of at least $40,000 per year. These high-paying jobs represented more than half of all jobs in 2017. Jobs in high-growth industries accounted for a large majority of gains during this time period. The number of *health care* jobs increased sevenfold (largely attributed to UPMC Children's), jobs in *professional, scientific and technical services* quadrupled, and jobs in *accommodation and food* services tripled.

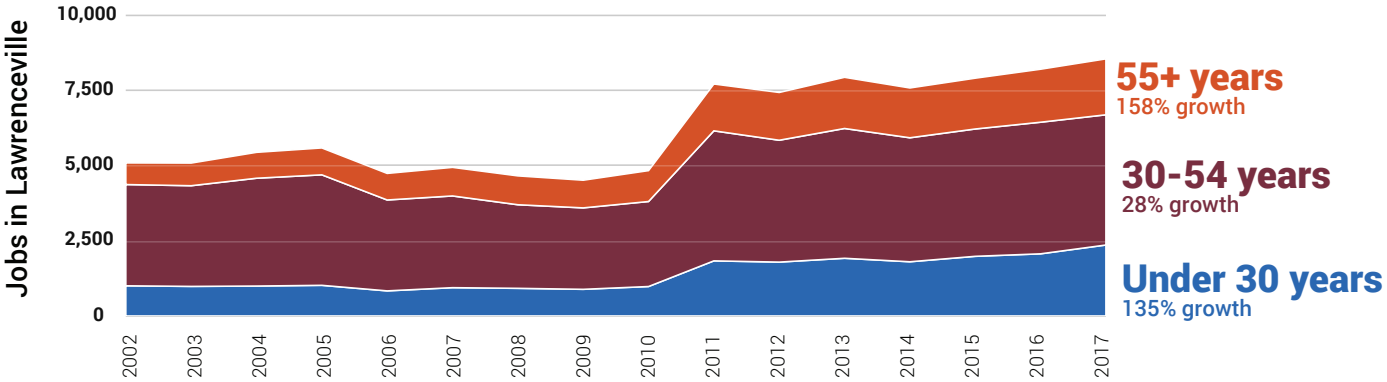
Jobs in health care and professional, scientific and technical services — anchored by NREC and other tech companies and UPMC Children's — stabilized what had previously been a trajectory of economic decline. New investments in restaurants and other accommodations and food services and retail businesses transformed the neighborhood, making Lawrenceville a vibrant part of Pittsburgh's cultural and culinary scene.

Many Lawrenceville residents have benefited from this period of local economic growth. Between 2002 and 2017, the number of Lawrenceville residents holding jobs increased by 24%, from 4,062 to 5,036. Resident employment increases in four industries accounted for the majority of employment gains, with health care and professional, scientific and technical services sectors making the largest gains. The number of neighborhood residents employed within the professional, scientific and technical services industry doubled from 2002 to 2017, with NREC and other employers along Robotics Row driving this growth. Additionally, the number of Lawrenceville residents holding high-paying jobs increased by 1,767 during this period, a 283% jump from 2002 levels. Combined, these workers bring home tens of millions of dollars annually from their increased paychecks, leading to increased spending at local businesses and investment back into the neighborhood.

Jobs data comes from the U.S. Census Bureau Center for Economic Studies Longitudinal Employer-Household Dynamics (LEHD) program.

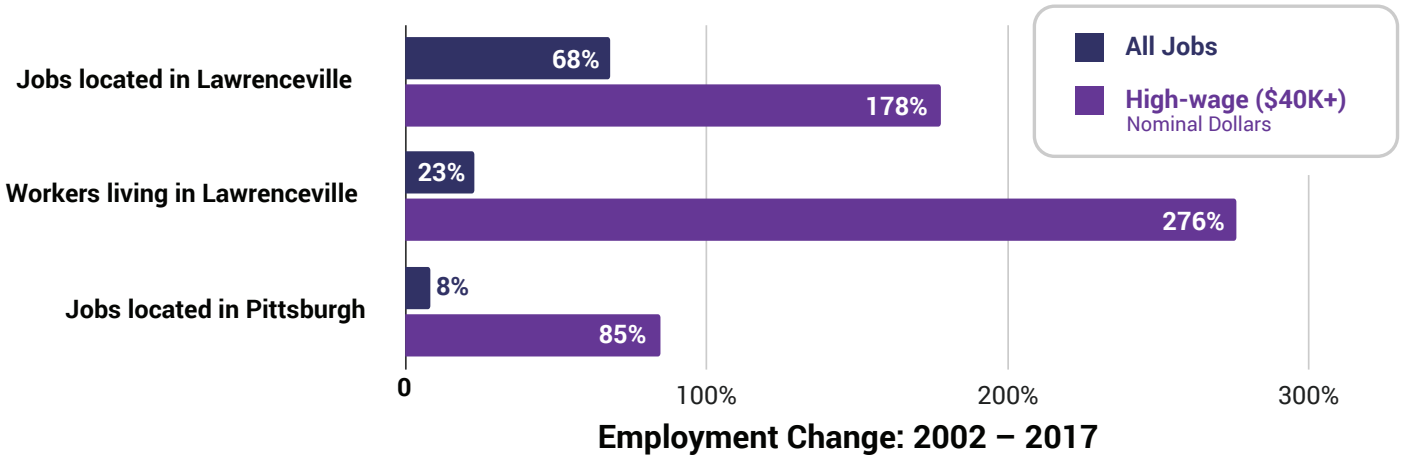
The Changing Age Dynamics of Lawrenceville's Workforce

Over the past 15 years for which data is available, Lawrenceville's workforce has changed considerably. All three major age groups of the workforce have grown, with the oldest age group growing most in percentage — partly driven by the aging of the population generally.



Growth in High-Wage Work

Job growth in Lawrenceville dramatically exceeded the city at large for both residents and workers, both in total jobs and specifically in high-wage jobs.



All data in above charts comes from LEHD and refers to primary jobs only.

Local Spending and Business Partnerships

In addition to its enormous impacts on the local economy and real estate market, NREC has directly supported businesses in the area through spending and operational partnerships.

Indeed, NREC has developed strong partnerships with a variety of businesses over its 25-year history. Many are international corporate behemoths, like CAT and John Deere, and it is these partnerships for which the institution is most widely known. NREC has also played an outsized role in the growth of the local robotics industry (see Section III. Alumni, Spinoffs and Business Partnerships). But NREC's impacts extend beyond high-tech and robotics partnerships. NREC also has a strong local network of business partners.

Some of these partners are service industry businesses that provide operational support to its staff and facilities. Some are food and accommodation businesses that cater NREC events or provide lodging to its guests. Others sell construction materials to NREC or perform machining and manufacturing for NREC projects.

In each of these areas of expenditure, NREC focuses its spending on local businesses, patronizing locally owned lumber mills, electrical supply shops, industrial engravers, machinists, print shops, hotels and restaurants (for NREC-provided catering). In addition, NREC staff members spend money at area restaurants and retail establishments. They generate enough demand for food that local businesses park food trucks outside of the facility on workdays.

Specific NREC Partnerships/Support

While this list is far from exhaustive, these businesses are good examples of local businesses where NREC has spent substantial money.

Suppliers:

- Allied Electronics, Inc.
- Atomatic Manufacturing Co.
- Graybar Electric Company
- Neff Automation
- Paul Lumber & Supply
- Precision Grit Etching and Engraving, Inc.
- Revival Print Company
- Schaedler Yesco Distribution, Inc.

Food/Accommodations:

- Deli on Butler
- Pesaro's Pizza
- Pittsburgh food trucks (at NREC facility)
- Salem's Market and Grill
- Shadyside Inn
- Sausalido Catering
- TRYP Hotel

Atomatic Manufacturing Co. is a machine shop located in Forest Hills (east of Pittsburgh) that has been doing business with NREC for the last 25 years. While it is only one example of such a partnership, it is a particularly strong one. NREC has spent hundreds of thousands of dollars at Atomatic, whose machinists have played critical roles in dozens of NREC's most significant projects. Atomatic's president, John Kindling (whose father founded the company in 1954), says that today robotics is probably Atomatic's primary customer base.

The Cost of Growth

While it is worth celebrating the large-scale economic transformation that this story represents, there have been some residents who may not have fully experienced all the same benefits as others. For example, this influx of economic activity and wealth has come at the cost of affordability for many existing residents and some businesses. Rising housing prices have substantially impacted renters, and many have been priced out of their homes. Homeowners may have benefited from rising property values, but as their taxes increase, those with limited incomes may be forced to sell. Others may be affected negatively simply by the changes in the cultural and physical landscape around them. And Lawrenceville has become a trendy business district that caters more to new residents and visitors than long-time residents. The final section of this report includes a few critical takeaways that consider how future development initiatives might learn from both the successes and shortcomings experienced in Lawrenceville.

NREC and its staff have generated spending at local businesses...

Over the last 25 years, NREC and its staff have spent money at local food and retail businesses in the neighborhood. Some of this spending is generated by proximity — such as when staff spend money for lunch or personal goods near the office. Some is generated directly through NREC, which hosts regular staff meetings with food provided by local businesses. Assuming NREC staff, on average, have purchased lunch locally twice a week, that's likely over $3 million in staff lunch spending over the last 25 years. NREC's direct purchases from restaurants are significant too. A weekly staff pizza lunch — provided by Pesaro's, a restaurant located a few blocks away from NREC in Lawrenceville since 2000 — has generated hundreds of thousands of dollars in spending at that one restaurant alone. All told, while a specific accounting is not practical, the combined effect of spending from NREC and its staff on local food and retail businesses is no doubt in the millions of dollars, a boon to the food and accommodations industry that has developed in Lawrenceville.

...and helped make Lawrenceville a go-to destination for food and retail.

Today, it's no secret that Lawrenceville is an opportune place to locate a restaurant. In 2019, two successful restaurateurs from Brooklyn, New York, were seeking a new location. They scouted cities and neighborhoods around the country looking for the right market and the right cultural vibe for their next project. Contender locations included in-demand areas of Atlanta and Philadelphia, but ultimately the location that rose to the top of their list was a small, vibrant neighborhood in Pittsburgh. They opened Walter's BBQ — located two blocks away from NREC in the heart of Lawrenceville — a year later in a building that had previously been an automart. The destination and its food have already become a favorite among NREC staffers and other local employees and residents. Asked about what went into the decision to locate in the area, owner Joel Bolden explained that the concentration of technology and robotics businesses had been a driving factor, because the concentration of high-wage, in-demand employment nearby "made the prospect [of developing Walter's] sustainable."

Images from Pesaro's Pizza Facebook page and Walter's Southern Kitchen (walterspgh.com)

Section VI.

Educational Programming

Beyond building robots that work in the real world, the National Robotics Engineering Center (NREC) also supports the broader development of robotics. NREC's programs increase access to robotics and are growing the future robotics workforce.

Carnegie Mellon Robotics Academy

NREC's Carnegie Mellon Robotics Academy (CMRA) has been providing services for educators and students in the local community and beyond since 2000. With a mission to use the educational affordances of robotics to excite students about science and technology, its work studies how buildable and programmable agents can be used to teach computer science & STEM skills at all ages.

Consisting of three "arms," the academy focuses on:

1. **Research, including design-based research on educational interventions**
2. **Development, including the LMS/CMS platform, workforce development and curriculum development**
3. **Outreach, including projects to inspire and teach at the K-12 level, as well as Out-of-School Time (OST) programs, teacher professional development, postsecondary, career education and other settings**

Workforce Initiatives | CMRA is also engaged in multiple initiatives around hiring and upskilling workers in advanced manufacturing and robotics careers. Examples of this work include those listed below.

RD-AIM-HIRE

With funding from the NSF Convergence Accelerator — which supports efforts to upskill vulnerable populations in manufacturing and connect them to the technical workforce — the Robotics Academy's project, Rapid Dissemination of AI Microcredentials through Hands-on Industrial Robotics Education (RD-AIM-HIRE), seeks to provide effective and deliverable machine learning (ML) curriculum for technician trainees with little or no STEM background.

AI Pathways Institute

The Artificial Intelligence Pathways Institute and Teen Accelerator Program (AIPI) partnered with PPG and the Boys and Girls Clubs of Western PA to hold AI camps for 40 students from historically underrepresented groups during summer 2019. After the completion of the summer programming, half of the students were offered paid internships to continue their prototype development.

SMART & SMART-ER

Smart Manufacturing and Robotics Technician Training (SMART) is a workforce development initiative that partners with industry to create micro-certifications and develop a pipeline of industry-certified workers ready to enter internships, apprenticeship programs, certificate and associate degree programs, and employment. Registered as an official PA pre-apprenticeship program, the initiative offers five unique micro-certifications and five online courses. **Approximately 5,000 students have completed or are working through at least one of the SMART courses online.** SMART Extended Reach (SMART-ER), a low-cost version of the initiative, works within community organizations. Funded by the Grable Foundation and partnering with organizations like Partner4Work and Auberle, **the program has reached over 200 students to date**.

CMRA also has broad outreach through its K-12+ curriculum offerings, largely via the CS-STEM Network (CS2N), a microcredential-oriented LMS/CMS platform for STEM curriculum. With 58 badged tracks, **over 75,000 badges** completed, more than two million achievements awarded **and 25,000 users certified**, CS2N has seen remarkable impact and success since its inception.

In addition to curriculum development, teacher professional development is a focus of CMRA. Training is delivered onsite, online or at teachers' locations, and **250-350 teachers participate annually**.

Partners in CMRA's work are located around the globe and include nonprofits, foundations, governments, corporations, educational institutions and robotics competitions. But many of these partners are specifically located in the Pittsburgh area, including:

- Advanced Robotics for Manufacturing
- Boys and Girls Club
- Butler Community College
- California University of Pennsylvania
- Community College of Allegheny County
- Community College of Beaver County
- Pittsburgh Public Schools
- Robert Morris University
- Sarah Heinz House
- Technology & Engineering Education Association of Pennsylvania
- Westmoreland Community College
- University of Pittsburgh
- YMCA

Through these local partnerships, NREC is not only a boon to its own institution, CMU, it is also playing a vital role in the region's educational and workforce development infrastructure.

Girls of Steel Partnership

From 2016 to 2019, NREC provided facilities representing $40,000 in annual support to Girls of Steel Robotics, a FIRST Robotics Competition Team with a mission to empower everyone, especially women and girls, to believe they are capable of success in STEM. The team, coached and supported by the Robotics Institute, was founded in 2010 with 24 girls and over the past decade has grown to over 60 participants. Encouraging girls to think "both technically and creatively," the organization provides opportunities for any interested girl — regardless of finances — to develop STEM skills while participating in national robotics competitions.

girlsofsteelrobotics.com

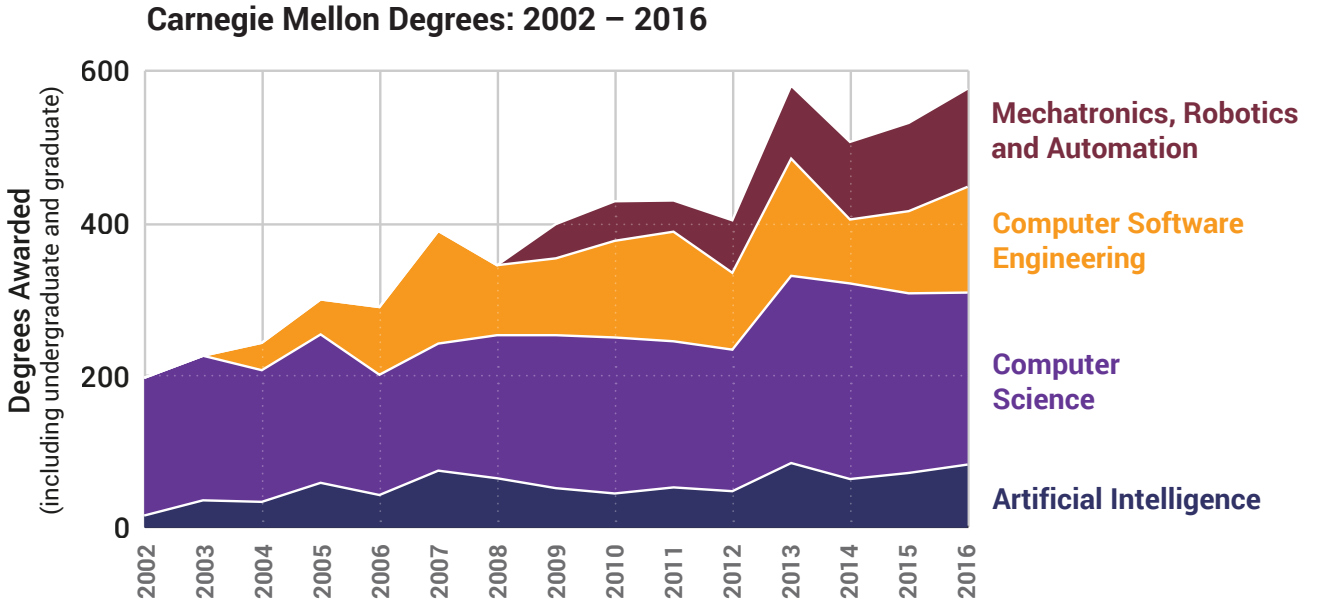
Robotics Careers: In-Demand, High-Wage Jobs

Beyond teaching transferable skills that can be applied to any career or industry, STEM education prepares the future workforce for jobs that are in high demand. The Bureau of Labor Statistics projects that between 2018 and 2028 the U.S. economy will add 859,000 jobs in STEM occupations, with STEM fields growing more rapidly than the economy at large — nearly 9% based on 2018 to 2028 projections, compared to 5% for non-STEM occupations. More importantly, the median wage of $86,980 for STEM occupations will be more than 2.3 times the median wage of $38,160 for non-STEM occupations.

While COVID-19 has dramatically influenced the national economic trajectory in the short term, and added uncertainty to most future labor force projections, it is likely that STEM careers will continue to grow, even just in the near future, with high demand and much greater potential for remote or partially remote work than the labor force at large.

And looking forward, there are not enough workers trained to succeed in STEM fields. According to a 2019 survey conducted by Modis, 80% of decision makers in engineering and technology fields had "significant concern" about a talent gap in their field.

NREC's efforts to prepare a future workforce for careers in robotics and other STEM fields will support a growing industry as well as a new generation of talented young people. Given NREC's role in applied robotics research, it is at the end of a robust pipeline of talent that Carnegie Mellon has been evolving for decades. The work at NREC weaves together a variety of disciplines in computer science and engineering that includes the Robotics Institute, the College of Engineering and the School of Computer Science. Over the 15 years from 2002 to 2016, the degrees awarded at CMU in key fields have tripled (see below), and through their partnerships, NREC and the university can continue to position the Pittsburgh region to be a celebrated hub of STEM talent for years to come.



Source: Education Data Explorer (Version 0.8.0), Urban Institute, Center on Education Data and Policy. Data from the U.S. Department of Education Integrated Postsecondary Education Data System.

Section VII. **Lessons Learned**

The final section of this report contains a brief overview of several key lessons learned from the preceding analysis of NREC's development and economic impact — locally, regionally and beyond. These lessons are not meant to be prescriptive or overly detailed, but insofar as NREC offers an example for future innovative academic institutions or similar development work, the following takeaways should be critically considered.

Engage early with local partners.

Establishing relationships with local businesses led to several important benefits for NREC. Relying on local machine shops, hardware stores and manufacturing support businesses not only made it easier for NREC to carry out some of its more challenging projects, it also bought the institution goodwill in a community where it might otherwise have been seen as an outside actor. Further, by concentrating purchases (e.g., food) and services contracting (e.g., janitorial services) among local suppliers, NREC helped to build up the economy of the area. Over time, these purchases added up to substantial investments, all the while making the area more attractive for potential employees and partner businesses.

NREC's limited early engagement with neighborhood groups and other socially oriented organizations also paid off in similar ways, and the imperative remains to engage more intentionally and purposefully in the future.

Public investments can leverage private dollars, especially in the long term.

In its early years, NREC was largely reliant on public funding and support — both from NASA and from state and local governments. The percentage of NREC's budget that came from public sources remained relatively high for its first decade of existence. Over time, however, private investment increased, and many private companies returned again and again to NREC, delighted with the results of their investments. Still, the impact that early public investment had is seen not only in the later direct investment into NREC from private companies. It is also, and perhaps more significantly, seen through the reach and impact of NREC's IP and inventions, as well as through the many companies founded or led by NREC alumni. These impacts have global reach, but they are particularly concentrated in the Pittsburgh region, and therein lies the bulk of the enormous return on the public's early investment in NREC.

Be patient and build the ecosystem: An institution can be both catalytic and understated.

NREC's presence went largely unnoticed outside of the world of robotics and economic development for many years, during which time it dramatically influenced the trajectory of the region's economy. That is certainly not the only model for the development of a successful technology-oriented institution, but it offers an important lesson: Making noise is not a good proxy for long-term impact.

Institutional proximity matters, but so does distance.

The robotics and tech ecosystem that developed near NREC required a lot of space, which the vacant and underutilized industrial real estate of Lawrenceville and the Strip District provided. Locating NREC closer to CMU's main campus would likely have led to a very different physical and economic landscape.

An active, walkable neighborhood is a critical asset.

Establishing NREC in Lawrenceville — as opposed to a more remote industrial locale (which might have seemed like a strong choice for a host of reasons: privacy, cheap land/construction, room to grow) — meant the growth of the robotics industry in Pittsburgh occurred in an urban setting and likely generated a much more significant economic impact. That context mattered greatly as the industry matured in the region and as Lawrenceville and the Strip District became sought-after places in which to locate businesses, largely due to the walkability of the area.

Much of that was a function of preexisting development patterns, incidental to NREC's development, but NREC came to play a role in making the surrounding area inviting for visitors, employees and residents. Led by NREC staff member Jim Martin, NREC helps to maintain the riverfront trail that exists on and near its property, which is an important asset for both NREC staff, who regularly use the trail, and neighborhood employees/residents. But this type of engagement would have benefited from earlier support and planning from the university. Small investments in infrastructure might have significantly influenced the physical development of the neighborhood, and in so doing, made it easier for residents and visitors to access the river as well as strengthened the physical connections between NREC and the business district on Butler Street.

Legacy is an asset.

It's easy to think of NREC as something completely foreign to the history that preceded it in Lawrenceville, but NREC benefited from Lawrenceville's industrial heritage in several important ways, as did the robotics industry in Pittsburgh generally. The physical infrastructure of the neighborhood — with large vacant areas, sturdy construction and high-bay buildings (both in the former foundry that NREC inhabits and elsewhere) — proved quite well-suited to the development of robotics and advanced manufacturing businesses in the area, as did the area's human infrastructure, with local manufacturing and machining know-how directly contributing to the success of NREC's projects.

Be aware of unintended consequences.
(Unintended does not always mean unpredictable.)

Development does not happen in a vacuum. Even when development is desired, it can unleash market forces that change a community in unexpected ways and/or generate negative impacts on residents. Major institutional investments will have consequences, and those institutions should consider how they will respond to those consequences (with what resources and partners), should they occur.

In Lawrenceville in 1995, gentrification and traffic congestion were not of significant concern to the community. By 2010, it was apparent that neighborhood residents (renters, especially) and businesses risked negative effects from speculation and changing development patterns. In the interceding years, a more proactive approach to these concerns, as they became apparent, on the part of the university and its partners might have avoided or mitigated some of the negative impacts on the community. This relates closely to the previous lesson related to the engagement of local partners.

Build a sustainable business model (even if it's not a business).

NREC's success was decades in the making, so it was critical that it had a sustainable business model that allowed for flexibility in funding sources, limited bureaucratic and institutional barriers, and avoided burdensome cost structures in construction as well as in operations/maintenance.

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