Building Competitiveness in Tennessee's Life Sciences Industry

January 2020

RTI INTERNATIONAL

Executive Summary

What companies and industries will form the basis of Tennessee's economy 25 years from now, and what jobs will Tennesseans do that pay living wages that support families? Over the past three decades, Tennessee's economy has benefitted from a hard-working, entrepreneurial workforce, a low cost of living, and a business-friendly climate. Industry growth has come from both the recruitment of companies and the growth of homegrown startups that have seeded new industries for Tennessee—FedEx in logistics and distribution, HCA Corporation in healthcare management, and Richards Medical (today's Smith & Nephew) and Sofamor Danek (today's Medtronic) in orthopedics.[1] These factors, along with incentives and investments, have attracted significant manufacturing activity, corporate headquarters, and sales and distribution activity to Tennessee.

Nevertheless, what industry leaders, educators, and state policymakers know is that Tennessee cannot rest on its laurels. The U.S. industry base continues to shift in response to scientific and technological advances, automation, and global competition. Today, being a low-cost, business-friendly state is not enough to attract more R&D- and knowledge-intensive industries to the state or support the growth of R&D-intensive startups. In 25 years, with continued economic growth, Tennessee will have a very different relative cost profile, and the importance of other competitiveness factors—a highly skilled workforce—will be even more pronounced.

The life sciences sector is a good sector for the state of Tennessee to pilot a more comprehensive approach to economic development because it encompasses both industry segments where Tennessee has a more robust industry base and others where the critical mass of companies is not yet there and where the growth of startups will be critical. What does it take to maintain a competitive advantage that Tennessee has in an industry segment today, and what will it take to diversify and seed a new industry segment where all the pieces are not yet there? This study brings stakeholder-driven recommendations and best practices from other states to bear on these questions.

Tennessee's life sciences sector is relatively small, employing 32,633 people. By comparison, the entire manufacturing sector, which spans automotive manufacturing to medical device manufacturing, employs 330,000 people.[2] However, the life sciences sector is important to Tennessee economically because it is a high-growth, export-oriented sector. The average salary for a Tennessean employed in the life sciences sector is $81,672, which is 75% higher than the overall private sector average of $47,618.[3] The sector's value derives not only from its economic impact, but also its human impact—our quality of life is improved as a result of the replacement joints, more effective therapeutics, and less invasive medical procedures developed by life sciences companies.

Tennessee's life sciences sector includes four key industry segments:

- Biosciences logistics and distribution;
- Medical devices and equipment;
- Drugs and pharmaceuticals; and

[1] Although it has not generated any new industry sector, CTI Molecular Imaging is another Tennessee startup, founded in Knoxville in 1983, which was acquired for $1 billion by Siemens Healthcare Solutions in 2005. See "Siemens to buy CTI Molecular Imaging, Inc., for $1 billion," *Memphis Business Journal*, 14 March 2005, https://www.bizjournals.com/memphis/stories/2005/03/14/daily44.html.

[2] U.S. Bureau of Labor Statistics. 2019. Quarterly Census of Employment and Wages. Washington, DC: U.S. Bureau of Labor Statistics.

[3] Ibid.

- Research, testing, and medical labs.

Two of these industry segments are based on manufactured products—medical devices and drugs and pharmaceuticals—and the two other segments—logistics and distribution and research, testing, and medical labs—provide critical services in the supply chain of the first two segments.

Of the four industry segments, the full economic development impact and footprint of the medical device segment is seen in Memphis. Memphis is home to original equipment manufacturers (OEMs), contract manufacturing and component suppliers, and logistics and distribution facilities. The types of jobs supported by the orthopedics industry span a variety of skill levels, educational certifications and degrees, job roles, and salary categories. The industry leverages a mature but growing global market, which is reflected in Tennessee's annual exports of $3.34 billion a year.[4] Medical devices is Tennessee's largest manufacturing-based life sciences industry segment, and industry growth (measured by employment) has kept pace with U.S. industry growth in this sector (5%).[5]

RTI International recommends the following actions to maintain competitiveness of the medical device industry and to maximize its economic development impact:

1. Manufacturing workforce: Work with the medical device industry and community colleges to pilot new approaches to recruiting high-demand instructors and giving students access to industry-grade equipment on which to train.
2. Workforce pipeline/student awareness: Convene a best practices summit in Memphis to share how the medical device industry and other related industries have worked with schools to design effective student outreach activities and successful industry days with hands-on programming.
3. STEM, business, and regulatory talent pipeline: Support critical, major investments in physical space and research support to help the University of Memphis achieve its goal of Tier 1 research status to grow the region's entry-level STEM, business, and regulatory talent pipeline.
4. Innovation ecosystem: Support university–industry research collaboration, innovation, and startup activity in high-growth areas adjacent to orthopedic impacts, such as surgical robotics, orthobiologics, and regenerative medicine.

In contrast to Tennessee's orthopedics industry, drugs and pharmaceuticals, medical devices outside of orthopedic implants, health tech, and biological research and testing for drug discovery are emerging industry segments. To build a critical mass of activity in other life sciences industry segments, Tennessee will need to focus on developing the ecosystem that supports scalable startups and attracts other young, innovative companies and entrepreneurs to Tennessee. As a starting point, RTI recommends two activities:

1. Develop a life sciences sector strategy that emphasizes all three economic development pillars: recruitment, retention and expansion, and growth of startups. TNECD can play a lead role in developing a life sciences sector strategy for the State of Tennessee by engaging in and documenting key findings from a targeted customer discovery process for both industry segments in which Tennessee has existing strengths, as well as for emerging industry segments. This builds upon the work and knowledge of TNECD's industry cluster business directors and regional offices. Supporting the growth of emerging industry segments will likely require a different approach and different types of incentives or innovation programs than the State of Tennessee has emphasized in

[4] Tennessee Department of Economic and Community Development, 2019. International Business. Accessed 12/1/2019 at https://tnecd.com/advantages/international/

[5] TEConomy/BIO. *State Biosciences Industry* reports, various years.

the past. Outreach to NC Biotech and the NC Department of Commerce, BioCrossroads and the Indiana Economic Development Corporation, or other states with strong life sciences sector strategies could be helpful in terms of lessons learned.

2. Include a capital initiative as part of this strategy. In the life sciences sector, startup acquisitions are a major mechanism by which states recruit larger companies with a global footprint to their state. In analyzing Tennessee's life sciences startup ecosystem, the fact that Tennessee has only two human health life sciences–focused venture capital (VC) firms with active funds today (compared with four active funds 6 to 8 years ago) is a major ecosystem limitation and weakness. Addressing gaps in capital for technology commercialization and startup VC financing will be important for building Tennessee's life sciences competitiveness. RTI recommends convening a meeting of life sciences–focused VC firms, startup founders who have had successful exits, and LaunchTN to develop a new capital initiative that incorporates the lessons learned from the design and implementation of previous programs.

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Background

About This Study

The Tennessee Department of Economic and Community Development (TNECD) and key stakeholders actively support and promote Tennessee's life sciences sector with the goal of positioning Tennessee as a competitive hub for life sciences activity. In September 2019, TNECD contracted with RTI International to perform an informed, objective assessment of where Tennessee's life sciences sector is today and to use a stakeholder-driven process to identify challenges and opportunities, as well as recommendations, for supporting further growth and development of the sector. This study sought to answer questions, such as: What are the key life sciences industry segments? What has been their recent economic performance? How do they compare nationally in terms of size and positioning for growth? The study also focused on identifying initiatives that the State of Tennessee can pursue to address key challenges and opportunities. The recommendations presented in this report draw heavily on the ideas offered by industry and other stakeholders, as well as best practices from other states.

Research Methods

RTI International analyzed a variety of economic and industry data, patent data, venture capital (VC) data, and academic research expenditure data. Data sources included the TEConomy/BIO *State Bioscience Industry* reports; National Science Foundation Higher Education Research and Development Survey; U.S. Patent and Trademark Office database; and Pitchbook Venture Capital, Private Equity, and M&A Database. A key focus of this study was to solicit stakeholder input and ideas. RTI interviewed 45 individuals representing Tennessee life sciences companies (both established and startup companies), life sciences–focused VC firms, university tech transfer office leadership and key university administrators, the Joint Institute of Biological Sciences at Oak Ridge National Laboratory, life sciences industry organizations, and others. As part of this study, RTI toured the Smith & Nephew and Elos Medtech facilities in Memphis; visited the Cumberland Emerging Technologies incubator in Nashville; facilitated a life sciences executive roundtable focus group; presented preliminary findings at the Life Sciences TN Conference on November 14, 2019; and presented initial findings again at a medical device industry stakeholder meeting in Memphis organized by the Greater Memphis Medical Device Council on December 2, 2019.

About RTI International

Based in Research Triangle Park, North Carolina, RTI International is a 501c3 nonprofit research institute. We are a leading force for public policy providing government, nonprofit, and private-sector clients with independent and objective research, analysis, and strategic advice. RTI's mission is to improve the human condition by turning knowledge into practice. Our team for this study is based in RTI's Center for Applied Economics and Strategy and included Jennifer Ozawa, Naomi Taylor, and Michael Hogan. What sets RTI apart from other consulting firms is the diverse, multidisciplinary skill sets and subject matter expertise we bring to projects. Our expertise spans industrial competitiveness, economic development, research and innovation, and entrepreneurial ecosystems.

Why Does Tennessee Care About the Life Sciences?

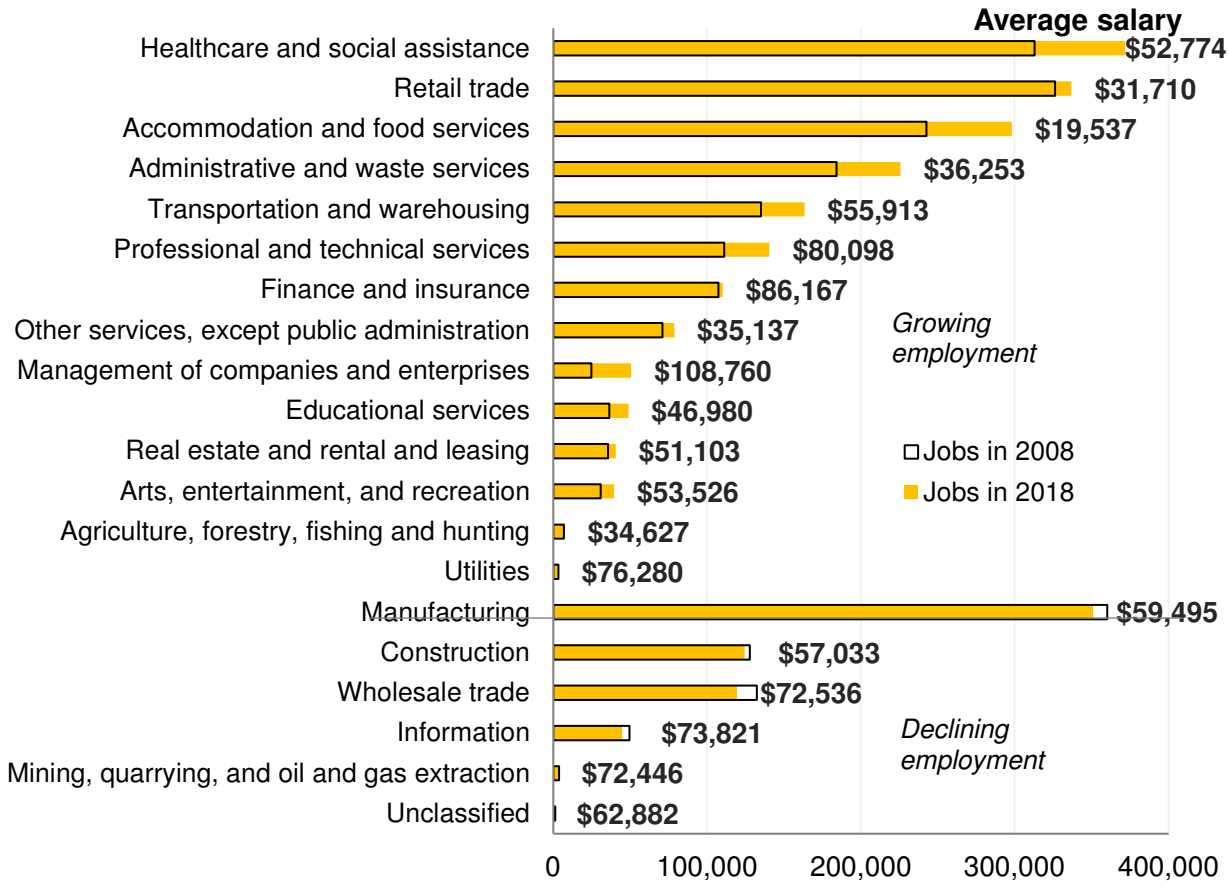
For the purposes of this study, Tennessee's human health life sciences sector is defined to include medical devices and equipment; drugs and pharmaceuticals; bioscience logistics and distribution; and research, testing, and medical labs. It is a relatively small sector, employing 32,633 people.[6] However, the biomedical life sciences is an important sector for Tennessee because it is a high-wage, high-growth, export-oriented sector and one in which the state has competitive industrial and research strengths on which to build. The average salary for a Tennessean employed in the life sciences sector is $81,672, which is 75% higher than the overall private-sector average of $47,618.[7]

Successful economic development hinges on the continued growth of higher-wage companies, industries, and jobs over time. An analysis of the changes in Tennessee's industry base over the past 10 years (Figure 1) indicates that many of the largest, highest-growth sectors have lower average salaries. In 2018, retail trade was Tennessee's second largest industry sector with 337,000 jobs (average salary of $31,170), accommodation and food service was the third largest with 298,000 jobs (average salary of $19,537), and administrative and waste services was the fourth largest with 226,000 jobs (average salary of $36,253). The largest employer across the state, healthcare and social assistance, employed 372,000 Tennesseans with a higher average salary of $52,774.

Conversely, some industry sectors that pay higher average salaries lost jobs over the past 10 years: manufacturing lost 9,000 jobs (average salary of $59,945), and wholesale trade lost 13,000 jobs (average salary of $72,536). Life sciences companies are found in multiple industry sectors: professional and technical services (average salary of $80,098), management of companies (average salary of $108,760), and manufacturing (average salary of $59,495).

[6] Latest available data are 2016 from TEConomy/BIO. 2019. Investment, Innovation and Job Creation in a Growing U.S. Bioscience Industry, 2018. Based on U.S. Bureau of Labor Statistics, Quarterly Census of Employment and Wages.
[7] U.S. Bureau of Labor Statistics. 2019. Quarterly Census of Employment and Wages. Washington, DC: U.S. Bureau of Labor Statistics.

Figure 1. Change in Employment and Average Wage of Tennessee Industry Sectors, 2008–2018

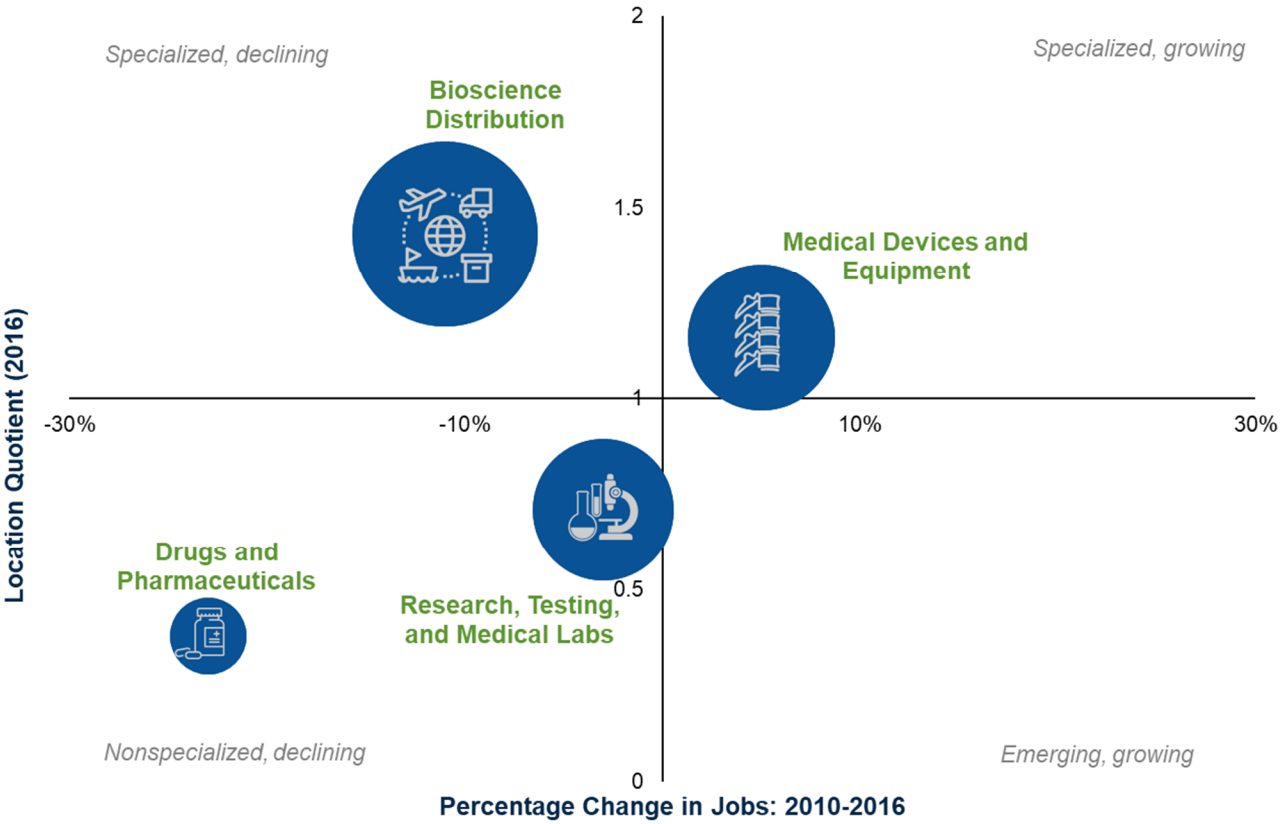


Source: U.S. Bureau of Labor Statistics. 2019. Quarterly Census of Employment and Wages. Washington, DC: U.S. Bureau of Labor Statistics.

How Are the Four Life Sciences Industry Segments Performing?

Tennessee's four life sciences industries—biosciences logistics and distribution; medical devices and equipment; research, testing, and medical laboratories; and drugs and pharmaceuticals—are different sizes, are at different stages of development, and have exhibited mixed employment performance over the most recent period for which data are available: 2010 through 2016. **Figure 2** compares the four industry segments by total employment size (i.e., size of the blue circle); percentage change in employment from 2010 through 2016; and location quotient, which indicates how concentrated or specialized Tennessee employment in each industry sector is vis-à-vis the national average (LQ=1).[8]

Figure 2. Tennessee's Life Sciences Industry Performance and Growth Trends, 2010–2016



Source: Battelle/BIO and TEConomy/BIO. multiple years. *State Bioscience Industry* reports.

[8] The location quotient is a measurement of the concentration of employment in a geographical area. A location quotient equal to 1.20 or higher indicates a "specialized" sector in an area.

Biosciences Logistics and Distribution

Bioscience logistics and distribution is the largest life sciences industry segment in Tennessee, employing 13,739 people. This industry segment supports manufacturers of medical devices and equipment, drugs and pharmaceuticals, and medical supplies through wholesale, logistics, and distribution activities. It represents part of the value chain for these other product-oriented segments. For example, in the orthopedics industry, for each knee replacement surgery, multiple sizes of replacement knees and surgical instruments are included in the knee replacement kit that is shipped to the orthopedic surgeon. The knee sizes and instruments that are not used during the procedure are shipped back to the company post-surgery. One finds major warehouses, logistics, and distribution facilities for several large orthopedic original equipment manufacturers (OEMs) in Memphis, as well as contract logistics and distribution providers.

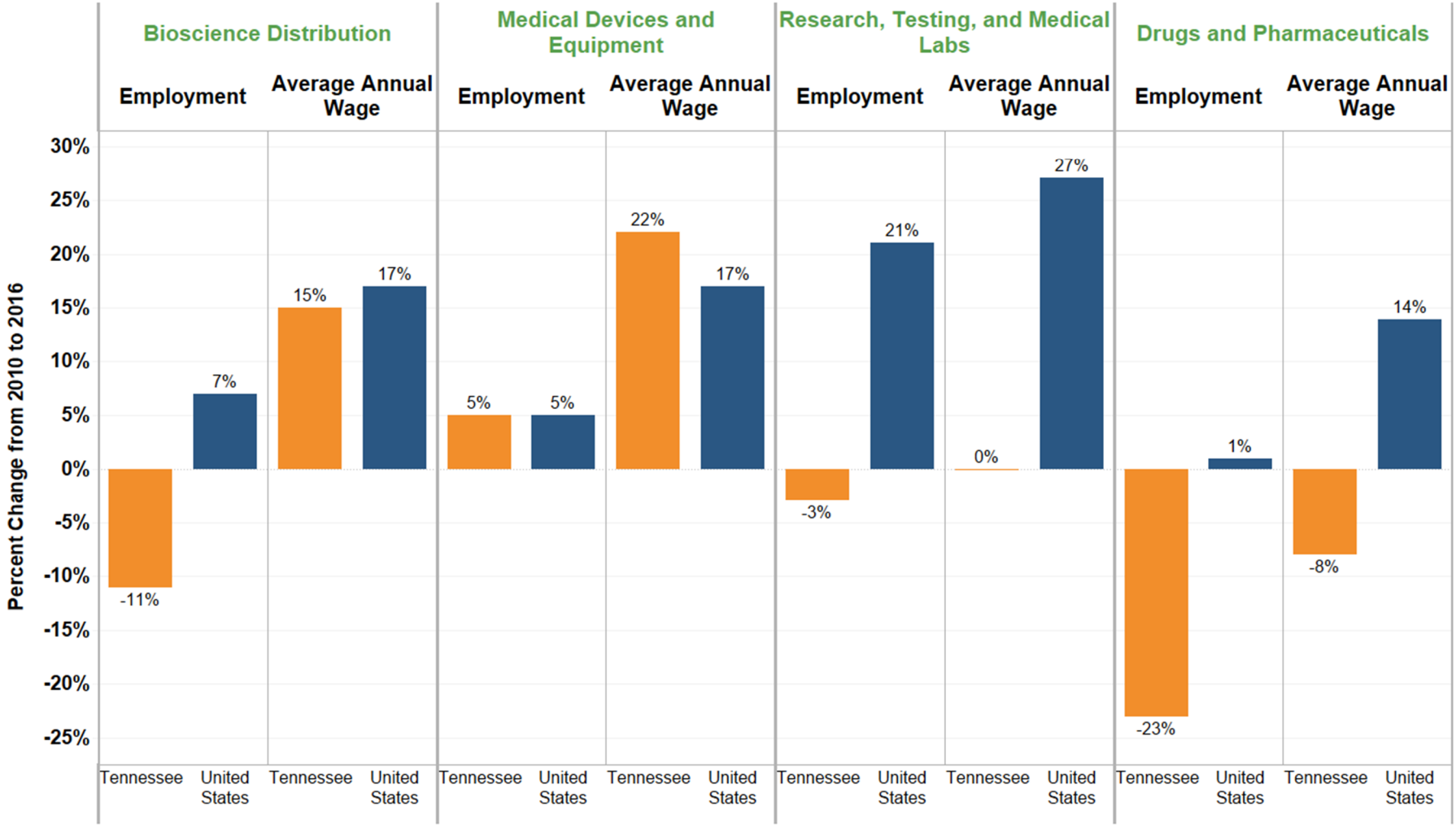
A major competitive advantage for Tennessee in this segment is the location of the FedEx Corporation headquarters in Memphis. FedEx employs 11,000 people at its FedEx Express World Hub in Memphis, and a $1.5 billion FedEx Memphis Hub modernization project is currently underway at the Memphis International Airport.[9]

Tennessee's concentration of employment in the biosciences logistics and distribution segment is high with a location quotient of 1.43 (1.0 is the national average employment in the industry as a share of total private-sector employment). However, employment in the bioscience logistics and distribution segment declined by -11% from 2010 through 2016, as shown in **Figure 3**. By comparison, employment in this industry segment nationally grew by 7% over this same time period. Whether there was an uptick in 2018 employment in Tennessee relative to the rest of the country remains to be seen. (The next TEConomy/BIO report with 2018 employment data will be released in 2020.) Average annual wage growth in this segment was similar to U.S. average wage growth for this industry segment.

Because of the decline in employment from 2010 through 2016, Tennessee's biosciences distribution employment ranking dropped to 11th in 2016 compared with 9th in 2010 and 7th in 2012 (see Appendix **Table A-4** for full ranking list). Nevertheless, the biosciences logistics and distribution industry segment remains Tennessee's largest life sciences segment and one in which Tennessee has a robust industry base and high degree of specialization. Future growth in employment in this segment depends on overall U.S. economic conditions, trade and manufacturing activity, workforce availability, and automation.

[9] Note that FedEx's employment is not included in the logistics and distribution data. See Appendix **Table A-2** for list of industry codes that comprise each life sciences industry segment's employment.

Figure 3. Comparing Percentage Change in Employment and Average Annual Wages Across Life Sciences Sectors in Tennessee and the United States, 2010 through 2016

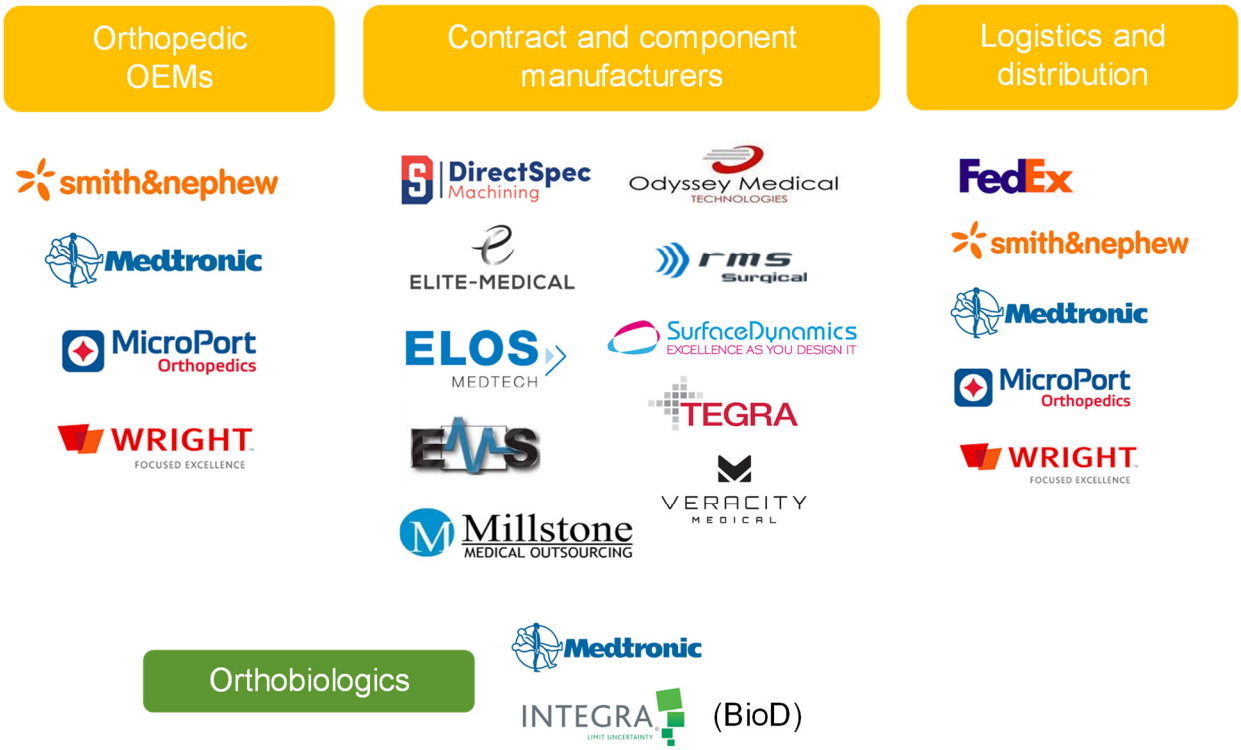


Source: Battelle/BIO and TEConomy/BIO. multiple years. *State Bioscience Industry* reports.

Medical Devices and Equipment

Medical devices and equipment is the second largest life sciences industry segment in Tennessee, with 8,541 Tennesseans employed in the industry at an average salary of $87,620. Although medical devices span pacemakers to imaging technology to insulin pumps and diagnostics, Tennessee's most prominent sector is the orthopedics industry in Memphis. Orthopedic OEMs and contract manufacturers account for over two-thirds of Tennessee medical device employment. **Figure 4** shows the range of companies comprising this industry by key segments in the supply chain: OEMs, contract and component manufacturers, and logistics and distribution.

Figure 4. Examples of Companies Comprising the Tennessee Orthopedics Industry Cluster and Supply Chain



Note: These examples are representative of the orthopedics industry but do not represent a comprehensive list.
Source: RTI International

While Tennessee ranks 16th nationally for medical device industry employment, the greater Memphis region (i.e., the metropolitan statistical area, or MSA) ranks 12th because of the presence of the orthopedics cluster (for a full ranking list of state and regional rankings, see Appendices **Table A-5** and **Table A-6**). The medical device industry segment is the only one of Tennessee's four life sciences industry segments whose employment growth kept pace with national industry employment growth from 2010 through 2016. Both grew by 5% over this period (see Appendix **Table A-1.** Tennessee vs. U.S. Life Sciences Industry Performance, 2010–2016 for actual employment figures). Average medical device industry wage growth in Tennessee (22% from 2010 through 2016) exceeded U.S. industry wage growth (17%). Memphis orthopedic companies indicate there is an excess demand for manufacturing workers (**Figure 3**).

Drugs and Pharmaceuticals

Drugs and pharmaceuticals is the smallest of the life sciences industry segments in Tennessee, employing just 2,339 people across 48 establishments. Tennessee's location quotient of 0.4 for drugs and pharmaceuticals employment indicates very nascent activity (**Figure 2**). Tennessee has a small number of established companies

in this sector operating across various segments of the value chain, as well as startup companies based on technology licensed from Tennessee universities. The following established companies are examples of revenue-generating firms:

- Cumberland Pharmaceuticals, Inc. (Nashville) specializes in the reformulation of existing drugs, which refers to acquiring, developing, and commercializing existing drugs for new indications;
- Harrow Health (Nashville) specializes in the compounding of drugs, which refers to combining or altering existing drugs to market them to specific populations;
- UPM Pharmaceuticals (Bristol) is a small molecule contract development and manufacturing organization;
- Pfizer has a sales office in Nashville and a distribution facility in Memphis; and
- GlaxoSmithKline has a distribution facility in Knoxville.

Example of pre-revenue startups that have raised VC rounds include the following:

- NuSirt Biopharma, which is focused on developing more effective treatments for type 2 diabetes and other metabolic diseases based on technology licensed from the University of Tennessee Research Foundation, has raised $21.1 million in multiple VC rounds and is in Phase 2A clinical trials.
- Appello Pharmaceuticals, which is focused on developing a treatment for Parkinson's that was licensed from Vanderbilt University, has raised a $10.5 million Series A round to support preclinical work.

Employment data show a decline in the Tennessee drugs and pharmaceuticals industry segment (−23% from 2010 through 2016) compared with 1% industry employment growth nationally and 14% industry wage growth nationally. However, the total size of the industry in Tennessee is so small that these growth rates are not very meaningful—a company of 23 people coming to Tennessee or shutting down would generate 10% growth or decline in employment because total industry employment is so small.

Research, Testing, and Medical Laboratories

Research, testing, and medical lab is the third largest industry segment in Tennessee, with 8,0147 employees. This segment includes contract research organizations that support drug development and clinical trials, as well as diagnostic testing and medical labs that support physicians' offices and hospitals. Nationally, this is a high-growth life sciences industry segment (21% from 2010 through 2016). By comparison, Tennessee's research, testing, and medical lab employment declined slightly by −3%, as shown in **Figure 3**.

Tennessee startup companies that fall in the drug discovery research support include the following:

- Protypia is a company based on technology licensed from Vanderbilt University that measures the proteins that are targeted by new cancer therapeutics. Different proteins can be expressed by individuals with the same form of cancer. If a new cancer drug is intended to work by targeting a specific protein, then identifying those cancer patients that express this protein before the clinical trial can improve the effectiveness of expensive trials and speed the development of new therapies.
- 490 Biotech is a company based on proprietary cell models licensed from the University of Tennessee Research Foundation that are used in preclinical drug discovery. These autobioluminescent cell lines are genetically programmed to "report" on biological events or interactions that affect their metabolic status in real time.

These companies are partially self-funded and generate revenue from initial customers. Both will need to raise VC or other financing to scale up their business development and their operational throughput to meet the growth in customer demand.

How Can Tennessee Build Competitiveness?

The long-term competitiveness of Tennessee's existing and emerging life sciences industry segments will be influenced by the planning, coordination, and action that government, industry, and higher education leaders take today. The data presented in the previous section showed that Tennessee has both mature industry segments with well-developed industry bases and innovation ecosystems (e.g., medical devices, specifically, orthopedic implants, and biosciences logistics and distribution) and emerging industry segments that require a comprehensive, ecosystem-based approach to develop and grow (e.g., drugs and pharmaceuticals and research, testing, and medical labs).

This section tackles two key economic development questions: What does it take to maintain a competitive advantage that Tennessee has in an industry today, and what will it take to diversify and build a critical mass of commercial activity in a new industry segment? RTI used the data and interviews conducted over the course of this study to perform a strengths, weaknesses, opportunities, and threats (SWOT) analysis of Tennessee's orthopedics industry and also emerging life sciences industry segments (e.g., drugs and pharmaceuticals, diagnostics, health tech, biological research and testing for drug development, etc.) to demonstrate how SWOT analyses can be used to identify gaps and opportunities on which recommendations can be based.

Orthopedics Industry SWOT Analysis

Strengths

The Memphis orthopedics industry designs and manufactures products for the trauma (i.e., bone fractures), spine, hip, knee, and extremities markets. As noted earlier, a key competitive strength for Tennessee is that the entire industrial value chain is present in Memphis from the OEMs, with a mix of R&D, strategic operations, and manufacturing functions, to contract and component manufacturers, to logistics and distribution companies and facilities. Memphis is home to FedEx Corporation, which is a key asset for orthopedic logistics and supply chain management. The city is also home to the Medical Education and Research Institute, one of the largest medical training facilities complete with a cadaver lab for research and surgical training, and the Campbell Clinic, a leading practitioner and teaching facility for sports medicine and orthopedics.[10]

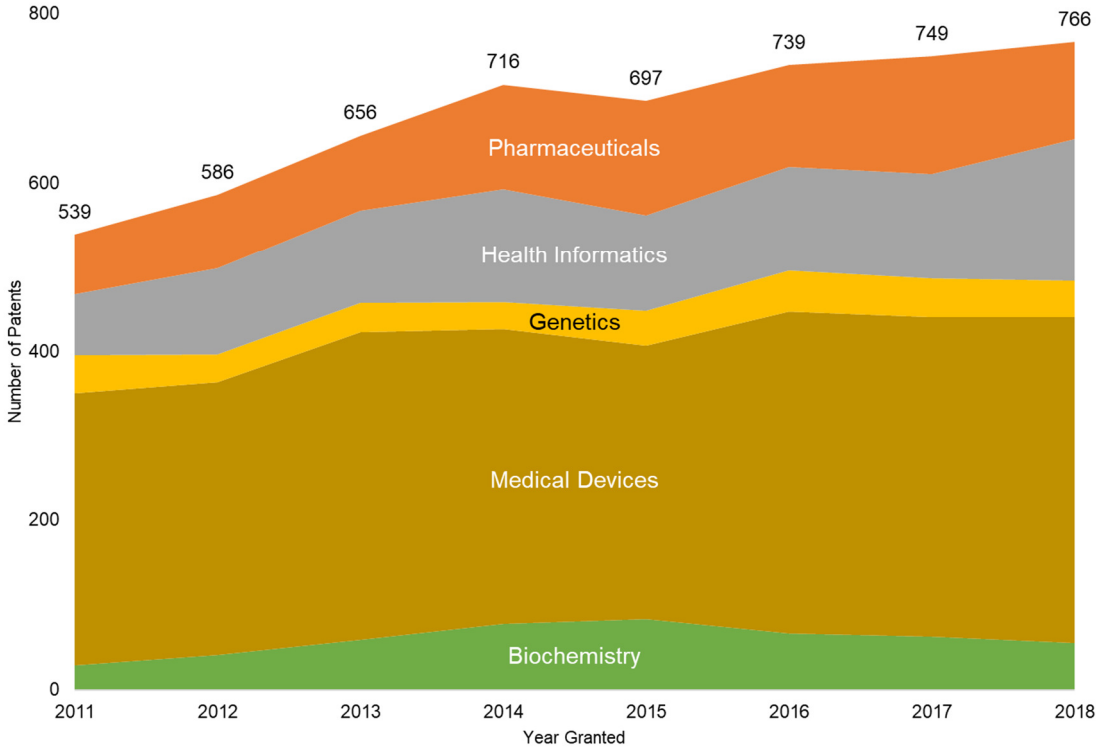
Because of the robust industry base, this industry segment has had significant innovation and startup activity. RTI's analysis of Tennessee patenting activity from 2011 through 2018 (**Figure 5**) found that medical devices accounted for 60% of total patents awarded to Tennessee inventors from 2011 through 2018. Medical devices patenting, over this 8-year period, was led by Memphis orthopedic companies (e.g., Medtronic [791], Smith & Nephew [259], and Wright Medical Technology [97]).[11] Among academic and research institutions, Vanderbilt

[10] Dr. Willis Campbell cofounded the American Academy of Orthopedic Surgeons (AAOS), serving as that body's first president.

[11] Smith & Nephew is the largest employer in the Memphis region, but the impact of Medtronic's R&D facility in Memphis is clearly seen in the patenting data.

University received 101 medical devices patents, followed by Oak Ridge National Laboratory (34), the University of Tennessee Research Foundation (25), and the University of Memphis Research Foundation (10) (**Table 1**).[12]

Figure 5. Patents Granted to Inventors in Tennessee, 2011–2018



Note: RTI analysis based on patents in which one or more inventors have a Tennessee address.
Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Table 1. Top 25 Assignee Organizations: Medical Device Patents Awarded to Tennessee Inventor, 2011–2018

Assignee Organization	Total Patents Granted	Average Granted per Year
Medtronic (Warsaw Orthopedic, Medtronic Vascular)	791	99
Smith & Nephew, Inc. (Memphis)	259	32
Individual inventors	242	30
Vanderbilt University	**101**	**13**
Wright Medical Technology, Inc. (Memphis)	97	12
Siemens (Knoxville)	67	8
Oak Ridge National Laboratory (UT-Battelle, LLC)	34	4
Gyrus ACMI, Inc.	32	4
FedEx (Memphis)	32	4
Zimmer, Inc. and Biomet Manufacturing, LLC (Memphis)	29	4
Microport Orthopedics Holdings Inc. (Memphis)	28	3
Eastman Chemical Company (Kingsport)	26	3

[12] The medical device patents for this last group of inventors span a wide range of diagnostic, imaging, surgical, and other technologies.

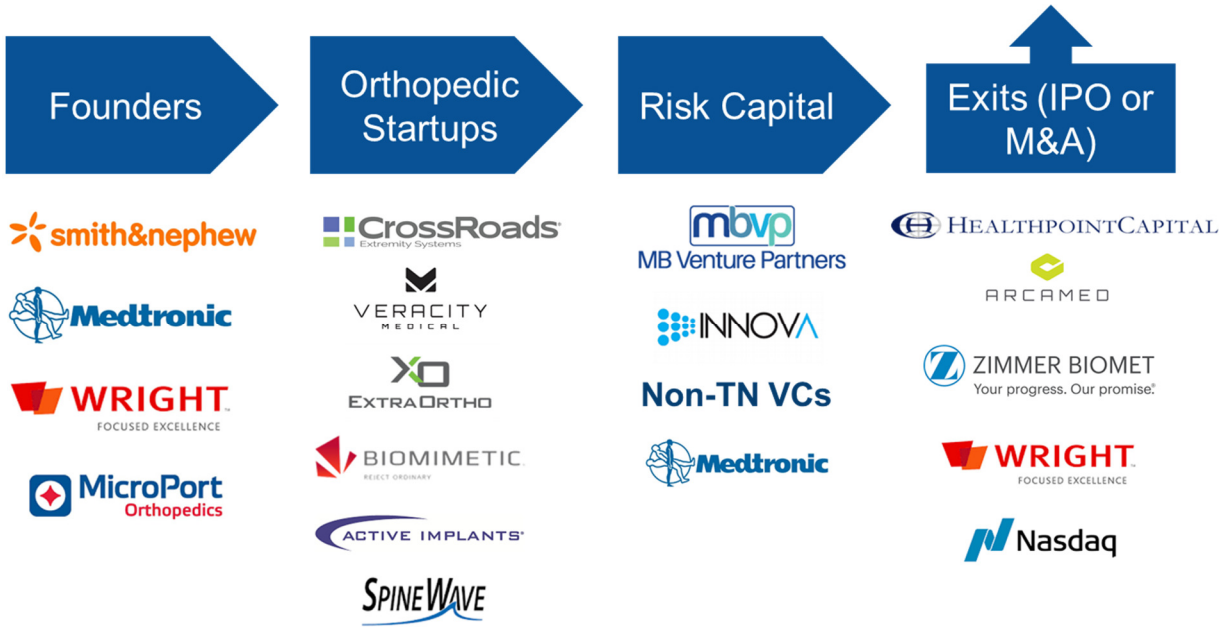
University of Tennessee Research Foundation	**25**	**3**
Active Implants (Memphis)	21	3
Legacy Ventures LLC	20	2
MRI Interventions, Inc. (Memphis)	19	2
Spine Wave, Inc. (Memphis, now CT)	18	2
CrossRoad Extremity Systems (Memphis)	15	2
Novartis AG	15	2
Smartvue Corporation	15	2
Permobil AB	14	2
The Trustees of the University of Pennsylvania	13	2
DePuy	12	2
Cyberonics, Inc.	11	1
Microwave Materials Technologies, Inc.	11	1
The University of Memphis Research Foundation	**10**	**1**

Note: RTI analysis based on patents in which one or more inventors have a Tennessee address. Blue bold indicates academic research institutions. Green bold indicates a federal research laboratory.

Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Venture-backed orthopedic startups are also active inventors (e.g., Active Implants was granted 21 patents, SpineWave 18, and CrossRoads Extremity Systems 15 from 2014 through 2018) (see **Figure 6**). RTI's analysis of Pitchbook data found that medical device startups represented the largest number of VC-backed life sciences startups in Tennessee from 2014 through 2018. Twenty-three Tennessee medical device companies raised $120.7 million in VC during this 5-year period (see **Table A-13**).

Figure 6. Tennessee's Orthopedics Startup Ecosystem



Note: These company examples are representative of the orthopedics startup ecosystem but are not a comprehensive list. BioMimetic is not a Memphis company. It was founded in Franklin, TN, near Nashville, by Sam Lynch.

Source: RTI International

Many founders of Memphis orthopedic startups that have had successful exits (i.e., initial public offering or acquisitions by larger firms) previously worked for Smith & Nephew, Medtronic, Wright Medical, or MicroPort Orthopedics.

Founders with industry experience bring the advantages of knowing the market, being positioned to identify niche opportunities where customer needs are not currently being met, and having more direct access to potential customers to validate new products. In addition to being a source of startup founders, the larger OEMs have also provided exits through the acquisition of startups (e.g., Zimmer Orthopedics [now Zimmer Biomet] acquired ExtraOrtho in 2011, and Wright Medical acquired BioMimetic in 2012). Being located in a region with significant research and startup activity is a competitive advantage for these larger companies who scan globally for new technologies in adjacent, high-growth areas.

Weaknesses

The Memphis orthopedics industry faces challenges maintaining the industry's growth in employment and production in response to growth in global demand. The Greater Memphis Medical Device Council (GMMDC) was formed, with support from the Bartlett Chamber of Commerce, in response to a critical shortage of machinists, finishers, packagers, and production operators. GMMDC's analysis identified problems in the curriculum being offered by community colleges, as well as in the lack of awareness of medical device job opportunities and career pathways by K–12 students, teachers, and parents.

According to hiring plan data compiled by the GMMDC, **the Memphis orthopedics industry will need to hire 476 workers over the next 3 to 5 years (2020 through 2024)** to meet customer demand. The Memphis orthopedic OEMs and some of the larger contract manufacturers have global operations. If they are not able to ramp up production in Memphis to meet customer demand, then they will be forced to shift production to another facility. Over time, this can erode corporate confidence in Memphis's competitiveness as an orthopedics manufacturing hub.[13]

In addition to manufacturing talent, the industry requires a broad range of R&D, engineering, regulatory, management, and business development talent, including entry-level talent produced by local and regional universities. The University of Memphis and the University of Tennessee Health Sciences Center offer a joint biomedical engineering degree program. The University of Memphis also offers mechanical engineering and other STEM degree programs that produce interns and graduates who are hired by Memphis medical device manufacturers. However, as enrollment has grown, the University of Memphis no longer has the physical space to accommodate the addition of classes. Lack of investment in University of Memphis facilities and research activities has resulted in western Tennessee being the only region in Tennessee that lacks a Tier 1 research university. Vanderbilt University and University of Tennessee–Knoxville are the Tier 1 research universities in middle and east Tennessee.

Opportunities

RTI interviews and data analysis identified clear opportunities for the State of Tennessee to evaluate:

- Increase the medical device industry's employment impact by continuing to work with industry, community college, and K–12 educators on workforce issues.

[13] See Appendix C, Greater Memphis Medical Device Council Letter to TNECD Commissioner Rolfe outlining a summary of meeting events.

- Support the University of Memphis's expansion of engineering and STEM enrollment and pursuit of Tier 1 research university designation through targeted capital investments and research support.
- Leverage Memphis's medical device startup ecosystem to recruit more innovative medical device and biotech startup companies to the region.

Threats

The Memphis medical device industry competes nationally and globally with other regional medical device hubs where targeted investments are being made in community colleges, research universities, and innovation programs to keep those industries anchored there. Just because an industry has developed and grown somewhat organically in the past does not mean it will continue into the future with no coordinated action or targeted investment. Attention needs to be paid to the strength of the ecosystem from both a workforce and an innovation perspective.

Today, the Memphis medical device industry is based on orthopedic implants. In the near term, the market will change in response to technological advances, such as surgical robotics and information technology/GPS, that are helping orthopedic surgeons know where to put the implants and how to put them there. The creation and commercialization of these technologies will mean that the orthopedic industry will need more electrical engineers and software engineers, whereas companies previously needed mechanical engineers and biomedical engineers. In the future, orthopedic innovation will be driven by the biological sciences and biomaterials with the aim of regenerating human tissue, such as cartilage. This field will require more workers with biology, chemistry, and biomedical engineering degrees.

Recommendations

The following recommendations address current and future competitiveness challenges. They build on grassroots efforts by industry, academia, and local economic development but require some state-level coordination and investment to meet the scale of the challenges:

1. Quality of manufacturing workforce training: The medical device industry has worked closely with local community colleges to improve the curriculum and industry certification of key programs, but finding highly skilled instructors and equipping all community colleges with industry-grade equipment on which students can train remain a challenge. The medical device industry is looking to pilot new approaches with the state to address these issues.
2. Workforce pipeline/student awareness: Greater awareness of medical device career pathways and educational requirements is needed among Memphis students, parents, and teachers. Some of this outreach is occurring through industry days and school tours already, and the GMMDC has developed a great website (https://gmmdc.org/) to explain different job types and training requirements. However, the state could facilitate the sharing of best practices from other industries with regard to working with schools, other types of effective student outreach activities, and successful industry days with hands-on programming.
3. STEM, business, and regulatory talent pipeline: Longer term, the medical device industry is concerned that Memphis is one of the few medical device hubs that lacks a Tier 1 research university. Research universities, like the University of Memphis, produce STEM graduates, as well as business graduates, and help Memphis attract talent from across Tennessee, the country, and the world. The medical device industry supports the University of Memphis's pursuit of Tier 1 research status and asks that the state provide the requisite investment in physical space, faculty, and research activity to achieve this growth and national distinction.

4. Innovation ecosystem: Today, the Memphis medical device industry is based on orthopedic implants. Five years from now, the high-growth segments of the industry will likely be in robotics and GPS/better positioning of implants, and 20 years from now the high-growth segments will be orthobiologics for regenerating musculoskeletal tissue. Memphis is home to the Medtronic Spine & Biologics R&D facility, and the patenting data have shown they are the largest inventor of pharmaceuticals (biologics) in Tennessee. The state can get ahead of the curve and build competitive advantage in some of these high-growth, adjacent areas by engaging with the Memphis Research Consortium and participating in the annual Musculoskeletal New Ventures conference to scan the musculoskeletal technologies that startups from around the country are commercializing.

Emerging Life Sciences Industry Segments SWOT Analysis

In contrast to medical devices and biosciences logistics and distribution, which are more mature industry sectors, the other life sciences segments—drugs and pharmaceuticals; research, testing and medical labs; medical device areas outside of orthopedics; and health tech—lack a robust industry base.[14] As shown in the Memphis orthopedics cluster, having multiple anchor companies in one geographic location can greatly enhance an innovation and startup ecosystem by germinating future startup founders and by serving as advisors, mentors, investors, and customers to startups. Healthcare services was outside the scope of this study, but it is worth noting that the same type of innovation and startup ecosystem found in Memphis orthopedics is also found in the Nashville healthcare services cluster.

The fundamental question for the state of Tennessee is whether to invest in a comprehensive ecosystem-building strategy to encourage the growth of other product-oriented life sciences segments, to double down on orthopedics industry growth and competitiveness, or to keep making incremental improvements. Some of the innovation ecosystem elements related to supporting the growth of startups and developing the State's innovation workforce are mutually reinforcing. The same type of investments the state could take to build innovation ecosystem capacity in emerging segments will also strengthen orthopedics innovation and startup activity.

The analysis presented below is a SWOT analysis of Tennessee's current positioning (i.e., enabling factors, organizational capacity, and programs) for developing a competitive advantage in emerging life sciences industry segments.

Strengths

There is strong stakeholder enthusiasm and grassroots momentum to engage in actions that catalyze more commercial life sciences activity in the Tennessee. This enthusiasm spans east, west, and middle Tennessee and draws its energy from stakeholders representing industry, startups and VC, research institutions, and government. It builds on:

- Growth in Tennessee's life sciences startup activity, VC investment, and successful exits;
- Stronger support for research commercialization and startups by academic institutions as part of their economic development mission; and
- Recognition of tangible outcomes from stakeholder investment of time and energy into building the life sciences community (e.g., Tennessee Life Sciences Mentor Network, Small Business Innovation

[14] Health tech was not a formal industry segment analyzed in this study because of the lack of industry definition and employment data available for this segment. However, RTI does present VC data that shows growth in health tech activity in the state.

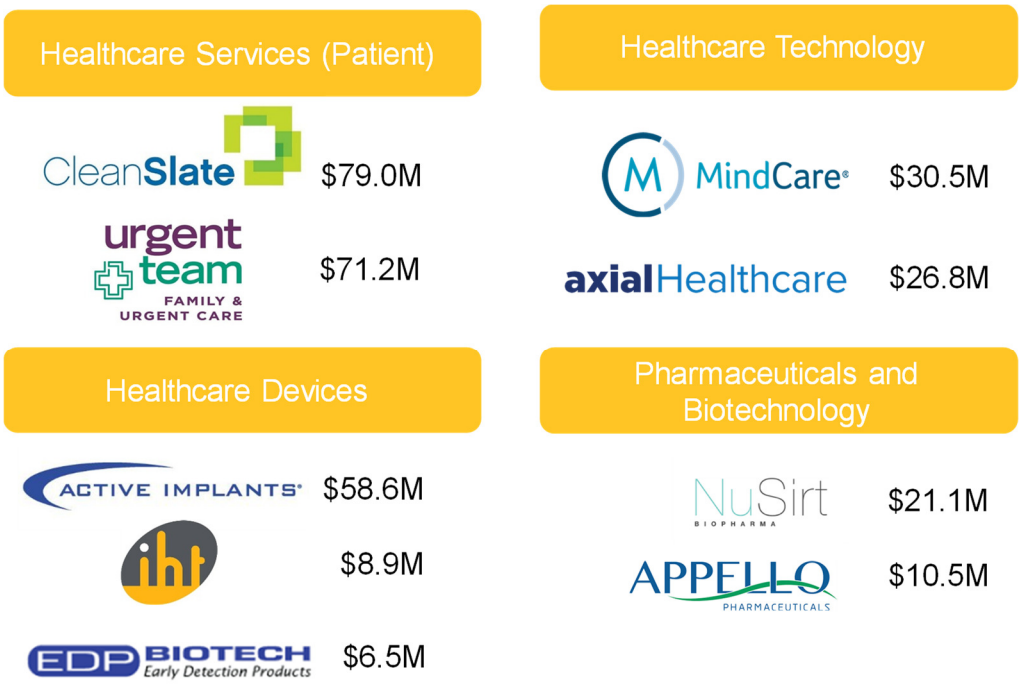
Research/Small Business Technology Transfer (SBIR/STTR) matching program, attendance at the Life Sciences TN Annual Meeting and annual Musculoskeletal New Ventures event)

RTI's analysis of Pitchbook data demonstrated the growth of venture-backed life sciences companies (see Appendices **Table A-13** and **Table A-14** for all data):

- From 2004 through 2008, seven medical device companies raised $37 million in VC. This number increased to 23 companies that raised $120.7 million from 2014 through 2018.
- From 2004 through 2008, one pharmaceutical and biotech company raised $1.5 million in VC. The number of companies grew to seven companies that raised $44.6 million from 2014 through 2018.
- From 2004 through 2008, five healthcare technology companies raised $7.4 million. This number grew to 16 companies that raised $156.7 million from 2014 through 2018.

Examples of Tennessee life sciences startups, representing different industry segments, are presented in **Figure 7**. The acquisition of local startups that commercialize a technology that solves a big problem for a big or high-growth market are increasingly the way states recruit global companies to locate in the state. In a patent analysis that RTI recently performed for the Governor's Office of Economic Development in Utah, we found that several global companies with high levels of patenting activity had come to Utah because of acquisitions of R&D-intensive Utah startups.[15] These included companies like Becton Dickinson and GE Healthcare in the life sciences, but also SanDisk and Symantec in flash drive and cybersecurity software.

Figure 7. Examples of Tennessee Life Sciences Venture-Backed Startups and Total VC Raised, 2014–2018



Source: Pitchbook Venture Capital, Private Equity, and M&A Database.

[15] Becton Dickinson's acquisition of Deseret Pharmaceutical, Harman's acquisition of DOD Electronics Corp., GE Healthcare's acquisition of OEC Medical Systems, L-3 Communications' acquisition of Unisys, SanDisk's acquisition of Fusion-io, and Symantec's acquisition of Altiris. Scruggs & Associates and RTI International. 2019. *Driving Economic Growth Through New Ideas and New Businesses*. Prepared for the Utah Governor's Office of Economic Development. Research Triangle Park, NC: RTI International. p. 45.

Large companies are looking for ways to accelerate their growth, and the acquisition of startups that have successfully commercialized products in new high-growth areas that complement the larger company's existing portfolio is a key way these companies are innovating to grow. **Acquisition of startups is what brought Siemens to Knoxville and what brought Smith & Nephew, Medtronic, and now Stryker to Memphis.**

Weaknesses

Despite the growth in life sciences startups in drugs and pharmaceuticals, imaging, medical devices outside of orthopedics, contract research and drug discovery tools, and health tech, the critical mass of larger anchor companies is not yet there. This is evident in private-sector patenting activity. Total pharmaceutical patenting is low compared with Tennessee's medical device patenting (see **Figure 5.** Patents Granted to Inventors in Tennessee, 2011–2018). In addition, the share of patents generated by academic research institutions is high, accounting for 42% of the Top 10 assignee organizations that were awarded pharmaceutical patents from 2011 through 2018, as shown in **Table 2**.

Table 2. Top Assignee Organizations: Pharmaceutical Patents Awarded to Tennessee Inventors, 2011–2018

Assignee Organization	Patents Granted	Average Patents Per Year
Medtronic (Warsaw Orthopedic, Inc., Medtronic Vascular)	149	19
Vanderbilt University (Nashville)	**127**	**16**
St. Jude Children's Research Hospital (Memphis)	**51**	**6**
University of Tennessee Research Foundation	**48**	**6**
Individual inventors	33	4
GTx, Inc. (Memphis)	27	3
Eastman Chemical Company	21	3
NuSirt Sciences, Inc. (Nashville)	21	3
Cumberland Pharmaceuticals Inc. (Nashville)	18	2
MonoSol Rx, LLC (now Aquestive Therapeutics in NJ)	18	2
BioDlogics, LLC (Memphis)	13	2
Samuel E. Lynch (Franklin)	7	1

Note: RTI analysis based on patents in which one or more inventors have a Tennessee address. Blue bold indicates academic research institutions, and green indicates a federal research laboratory.

Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Medtronic is the top corporate inventor of pharmaceutical patents (149 patents) because of its Spine & Biologics R&D facility in Memphis. Medronic is followed by Vanderbilt University (127), St. Jude's Children's Research Hospital (51), and University of Tennessee Research Foundation (48). GTx (27) was a venture-backed Memphis startup whose only clinical stage drug candidate failed a Phase 2 trial and shut down in 2018.[16] Cumberland

[16] Nichols, Meghan. September 2018. "Memphis company's stock plummets 90 percent in one day." *Memphis Business Journal*, 21. https://www.bizjournals.com/memphis/news/2018/09/21/memphis-companys-stock-plummets-90-percent-in-one.html

Pharmaceuticals (CPIX) is a small but NASDAQ-listed company focused on reformulations that is located in Nashville.

The absence of larger or more established pharma and biotech companies means that there are very few potential founders with industry experience and the networks required to raise VC to scale these companies. Therefore, VC investment in pharmaceuticals companies is also relatively low compared with VC investment in other life sciences companies for Tennessee. The seven Tennessee pharmaceuticals and biotechnology startups that raised VC from 2014 through 2018 represented only 9% of Tennessee's VC-backed life sciences companies and 7% of total life sciences VC investment from 2014 through 2018 (**Table A-10**). Nevertheless, this is still an improvement in activity relative to 10 years ago when only one Tennessee pharmaceutical company raised VC, according to Pitchbook data.

While it may be the case that "good companies get funded," it is also the case that:

- "So-so companies can get too much funding" in parts of the country where too many VC firms are competing for too few high-quality deals (this is a common criticism of the Bay Area), and that
- "Potentially good companies in the South and the Midwest may never get off the ground" because there is not enough early-stage risk capital to engage in customer discovery and generate data to know one way or another.

This past fiscal year the State of Tennessee increased its funding for the SBIR/STTR matching program to $3 million a year. The SBIR/STTR program is the federal government's seed fund for helping R&D-based startups commercialize new technologies via Phase 1 ($150,000) and Phase 2 grants ($1 million). Tennessee's SBIR/STTR matching programs aim to help R&D-intensive startups maximize this federal funding. LaunchTN provides small grants to Tennessee startups to hire consultants with experience writing SBIR proposals. SBIR grants are nationally competitive and difficult to win.

Tennessee has also launched two capital initiatives in the past to expand the availability of early-stage VC: TNInvestCo and the LaunchTN INCITE Fund. These capital programs did not target the creation of life sciences–focused VC firms or life sciences startups specifically. However, TNInvestCo resulted in the creation of four approximately $10 million to $12 million life sciences–focused VC funds. These funds were awarded to and managed by four Tennessee life sciences–focused VC firms: MB Ventures and Innova in Memphis and Mountain Group Partners and Tristar Technology Ventures in Nashville. Examples of successful exits from these TNInvestCo-supported investments include the following:

- ExtraOrtho, an orthopedic external fixation startup, was acquired by Zimmer in 2011.
- Diagnovus, a molecular diagnostics lab, was acquired by Aegis Sciences in 2015.
- CrossRoads Extremity Systems, an orthopedics startup, was acquired by Healthpoint Capital in 2019.

The challenge for Tennessee's life sciences startup ecosystem today is that only one of these four VC firms has a new fund that is actively investing in pharmaceutical, diagnostic, and health tech startups—Mountain Group Partners. TriStar Technology Ventures is no longer active. MB Ventures and Innova are making follow-on investment in portfolio companies from prior funds but have not yet raised new life sciences–focused funds. (Innova did raise $31 million for an agriculture innovation fund in 2017.)

Therefore, three of the four VC firms that were actively investing in new life sciences startups 6 to 8 years ago are not actively investing now. RTI identified one relatively new life sciences–focused VC firm, Solas BioVentures, which raised its first fund in 2014. Solas BioVentures is headquartered in Chattanooga. There are also angel

investors, and LaunchTN has a $5 million IMPACT Fund generated from the return on investment in its U.S. Treasury-supported INCITE Fund. However, the number of institutional VC funds in Tennessee that invest in biopharmaceutical, medical device, and health tech startups are down to two. This situation puts Tennessee in the "potentially good companies never getting off the ground" category, although a few may be able to attract institutional VC investment from out of state.

Opportunities

Tennessee's academic research institutions have embraced technology transfer and commercialization as a core economic development mission of the university system. Licensing to startups is one commercialization pathway, and there are many examples of Vanderbilt University (including the Vanderbilt Academic Medical Center) and the University of Tennessee Research Foundation (primarily University of Tennessee Health Sciences Center and University of Tennessee–Knoxville) licensing to Tennessee startups, as shown in **Table A-9** and **Table A-10**.

The challenge is getting industry and VC eyes on these technologies to know if there is market potential and to pair the technologies with teams (with industry and regulatory experience) that can commercialize them. A good development on this front is a $65 million collaboration between Vanderbilt University and Deerfield Management, a New York City–based life sciences investment firm. Deerfield has committed up to $65 million in promising Vanderbilt drug research and will make additional capital investments in any companies that spin-off from this translational R&D.[17]

There is also an opportunity, as part of a larger sector strategy, to tell a better story about life sciences in Tennessee and to continue to leverage stakeholders (in particular, representatives from industry and life sciences–focused VC firms) to recruit companies to Tennessee. A good life sciences story from a company recruitment perspective might center around Tennessee being a great place to accelerate product-oriented, life sciences companies as demonstrated by the growth of Tennessee's orthopedic implants cluster in Memphis. The message could be that Tennessee welcomes young, innovative companies looking for a business-friendly environment, sense of community, access to key players, and innovation-minded STEM graduates. Because of the goodwill and collaborative nature of individuals within Tennessee's life sciences community, it is also possible to leverage this network (e.g., if a company has a workforce question and wants to speak to another company in the same industry vertical, if a company has a startup financing or tax question and would be interested in talking to a VC firm or accountant who works with Tennessee startups). This type of network demonstrates community and access to prospective companies looking to accelerate their business.

Threats

The main external threat to Tennessee's emerging life sciences companies and ecosystem is from competitor states with more developed ecosystems or with better designed and executed strategies for developing their ecosystems.

In RTI's presentation of preliminary findings at the Life Sciences TN Conference in November 2019 (and presented again in the next section of the report), RTI noted that in the 1960s, North Carolina's economy was built around tobacco, furniture, and textiles manufacturing. Whereas Indiana's pharmaceutical industry developed by virtue of Col. Lilly establishing Eli Lilly and Company in Indianapolis in 1876, North Carolina had no

[17] See https://www.ancorainnovation.com/ to learn more about the Vanderbilt University-Deerfield Management drug development collaboration.

pharmaceutical companies in the state in the 1960s. However, today, North Carolina ranks third nationally for the size of its pharmaceutical industry employment.

States can develop a competitive advantage in knowledge-based and advanced manufacturing industries over time, but it requires a long-term vision and commitment and a good strategy backed by organizational capacity and investment. States can also lose a competitive advantage over time, and Tennessee should focus on not losing its competitive advantage in orthopedics.

Recommendations

RTI recommends two initiatives the State of Tennessee could take to build competitiveness and better position itself in emerging life sciences industry segments:

1. Develop a life sciences sector strategy that emphasizes all three economic development pillars: recruitment, retention and expansion, and growth of startups. TNECD can play a lead role in developing a life sciences sector strategy for the State of Tennessee by engaging in and documenting key findings from a targeted customer discovery process for both industry segments in which Tennessee has existing strengths, as well as for emerging industry segments. This builds upon the work and knowledge of TNECD's industry cluster business directors and regional offices. Supporting the growth of emerging industry segments will likely require a different approach and different types of incentives or innovation programs than the State of Tennessee has emphasized in the past. Outreach to NC Biotech and the NC Department of Commerce, BioCrossroads and the Indiana Economic Development Corporation, or other states with strong life sciences sector strategies could be helpful in terms of lessons learned.
2. Include a capital initiative as part of this strategy. In the life sciences sector, startup acquisitions are a major mechanism by which states recruit larger companies with a global footprint to their state. In analyzing Tennessee's life sciences startup ecosystem, the fact that Tennessee has only two human health life sciences-focused venture capital (VC) firms with active funds today (compared with four active funds 6 to 8 years ago) is a major ecosystem limitation and weakness. Addressing gaps in capital for technology commercialization and startup VC financing will be important for building Tennessee's life sciences competitiveness. RTI recommends convening a meeting of life sciences-focused VC firms, startup founders who have had successful exits, and LaunchTN to develop a new capital initiative that incorporates the lessons learned from the design and implementation of previous programs.

Benchmark: How Does Tennessee's Life Sciences Activity Compare with That of Peers?

Tennessee's largest and most specialized life sciences industry segments are biosciences logistics and distribution and medical devices. Table 3 shows the national ranking, number of establishments, total employment, location quotient (i.e., share of private sector employment in this industry segment in each state relative to its share of private sector employment nationally), and share of total U.S. biosciences logistics and distribution industry employment. Tennessee ranks 11th nationally in total biosciences logistics and distribution industry employment and has a high degree of specialization in this industry, as shown by a location quotient of 1.43, meaning employment in this industry is 43% higher in Tennessee than nationally. As noted earlier, this industry segment is anchored by FedEx in Memphis.**Table 3.** Biosciences Logistics and Distribution: Tennessee Employment Rankin vs Top 10 State, 2016

State	Rank	Establishments	Employment	Location Quotient	Share of U.S. Employment
California	1	3,858	57,076	1.04	12.2%
Texas	2	2,969	38,181	0.99	8.1%
Florida	3	3,018	36,155	1.28	7.7%
Illinois	4	1,881	26,058	1.31	5.5%
New Jersey	5	1,237	22,015	1.69	4.7%
New York	6	1,573	19,192	0.64	4.1%
Ohio	7	1,548	19,114	1.07	4.1%
Pennsylvania	8	777	16,549	0.84	3.5%
North Carolina	9	1,615	15,287	1.10	3.3%
Georgia	10	1,060	14,306	1.02	3.0%
Tennessee	**11**	**871**	**13,739**	**1.43**	**2.9%**

Source: Battelle/BIO and TEConomy/BIO. multiple years. *State Bioscience Industry* reports.

To benchmark Tennessee's total life sciences sector activity against a state with a similarly size population and cost of living, RTI compared Tennessee's life sciences industry employment against that of Indiana. **Table 4.** Comparing Life Sciences in Tennessee and Indiana, 2016 shows that Indiana's medical device employment is more than double Tennessee's. Warsaw, IN, is the largest orthopedics cluster in the country, anchored by the corporate headquarters and manufacturing operations of both DePuy and Zimmer Biomet. In drugs and pharmaceuticals, Indiana has eight times the employment of Tennessee because of the location of the Eli Lilly headquarters in Indianapolis, IN. Research, testing, and medical labs employment is higher than in Tennessee, but lower than expected given the presence of Eli Lilly. Employment in biosciences logistics and distribution (10,284 employees) is significantly lower than in Tennessee (13,739 employees).

Table 4. Comparing Life Sciences in Tennessee and Indiana, 2016

	Tennessee	Indiana
Population (2019 Census)	**6.77 million**	**6.69 million**
Cost of Living Index (2019)	**88.7**	**90**
Medical Devices and Equipment		
Establishments	138	155
Employment	**8,541**	**17,317**
Location Quotient	1.16	2.25
Average Annual Wage	$87,620	$67,793
Drugs and Pharmaceuticals		
Establishments	48	47
Employment	**2,339**	**17,862**
Location Quotient	0.38	2.78
Average Annual Wage	$82,145	$139,002
Bioscience Distribution		
Establishments	871	996
Employment	13,739	10,284
Location Quotient	1.43	1.02
Average Annual Wage	$83,527	$83,258
Research, Testing, and Medical Labs		
Establishments	467	482
Employment	8,014	8,955
Location Quotient	0.71	0.76
Average Annual Wage	$73,396	$69,873
Total Bioscience Industry		
Establishments	1,524	1,680
Employment	**32,633**	**54,419**
Location Quotient	0.92	1.70
Average Annual Wage	$81,672	$89,982

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* reports.

Comparing Tennessee with North Carolina also provides an interesting perspective (

Table 5). North Carolina is a much larger state than Tennessee with a higher cost of living driven by the rapid economic and population growth of the Research Triangle region. North Carolina's drugs and pharmaceuticals employment (20,656 people) is 10 times larger than Tennessee's (2,339 people) and also larger than Indiana's (17,862 people). North Carolina has very similar employment in medical devices to Tennessee, and its biosciences logistics and distribution employment is higher than Tennessee's. North Carolina has a robust research, testing, and medical labs segment and is known for its global contract research organizations like Quintiles (now IQVIA), PPD, PRA, and Syneos Health.

Table 5. Comparing Life Sciences in Tennessee and North Carolina, 2016

	Tennessee	North Carolina
Population (2019 Census)	6.77 million	10.38 million
Cost of Living Index (2019)	88.7	94.9
Medical Devices and Equipment		
Establishments	138	196
Employment	**8,541**	**8,411**
Location Quotient	1.16	0.79
Average Annual Wage	$87,620	$63,153
Bioscience Distribution		
Establishments	871	1615
Employment	**13,739**	**15,287**
Location Quotient	1.43	1.10
Average Annual Wage	$83,527	$91,048
Research, Testing, and Medical Labs		
Establishments	467	1862
Employment	**8,014**	**28,896**
Location Quotient	0.71	1.79
Average Annual Wage	$73,396	$93,432
Drugs and Pharmaceuticals		
Establishments	48	125
Employment	**2,339**	**20,656**
Location Quotient	0.38	2.34
Average Annual Wage	$82,145	$98,800
Total Bioscience Industry		
Establishments	1,524	3,798
Employment	32,633	73,251
Location Quotient	0.92	1.51
Average Annual Wage	$81,672	$86,608

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* reports.

Whereas Indiana benefitted serendipitously from the establishment in the late 1800s of pharmaceutical and medical device companies that became global Fortune 500 companies, North Carolina built a life sciences industry by virtue of a common, future-oriented economic development vision and commitment to a long-term strategy. How did North Carolina do this?

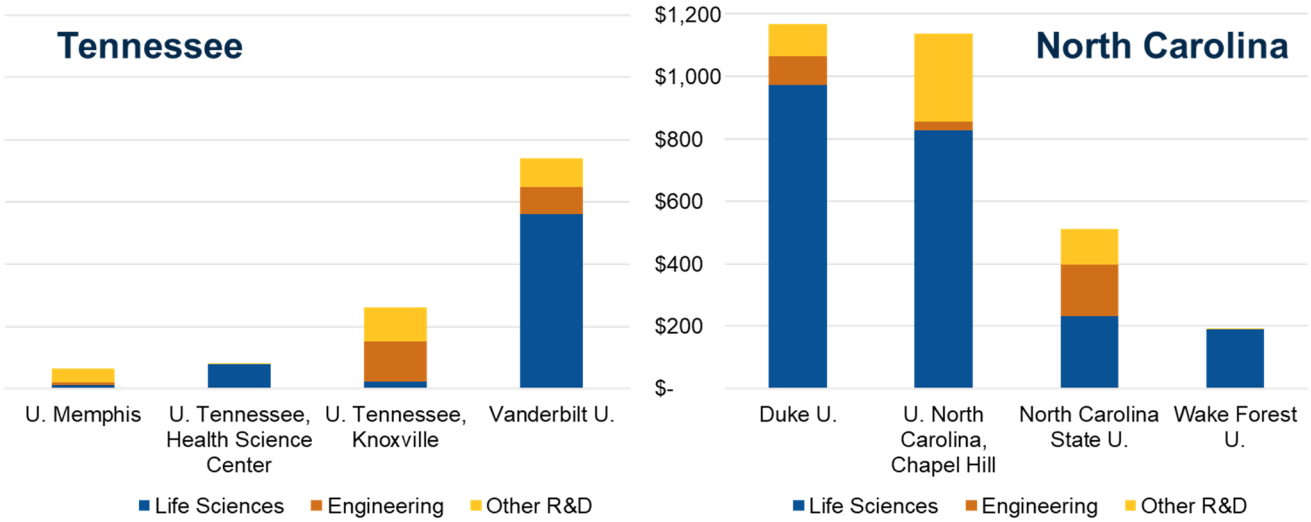
As John Hardin, Executive Director of the North Carolina Office of Science, Technology, and Innovation notes, "… at the time of Research Triangle Park's (RTP's) founding [in 1959], the region was not a large metropolitan area, it lacked a strong base of high-tech manufacturing, it had a low-skilled and relatively low-education level, and it had little tradition of entrepreneurial activity."[18]

What North Carolina did have in terms of assets was good timing; strong commitment by industrial, educational, and government leaders to take North Carolina in a technology-oriented direction; and the co-location of three

[18] Hardin, John. November 30-December 1, 2005. "Chapter 2: North Carolina's Research Triangle Park: Overview, history, success factors and lessons learned." *Proceedings of the Frontis Workshop*, Wageningen, The Netherlands. https://library.wur.nl/frontis/research_triangles/02_hardin.pdf

research universities—Duke University, North Carolina State University, and University of North Carolina at Chapel Hill—in close proximity to one other, with one of the country's first research parks located in the middle.[19] Comparing the total R&D expenditures by North Carolina's and Tennessee's four leading research universities is quite striking (**Figure 8**). In 2018, North Carolina's top four universities performed 3.1 times as much life sciences R&D and 1.3 times as much engineering R&D as Tennessee's top four universities.

Figure 8. Total R&D Expenditures by Four Largest Universities, FY2018 ($M)



Source: National Science Foundation. 2019. National Center for Science and Engineering Statistics, Higher Education R&D Survey, FY2018.

Hardin's history of RTP notes that Governor Hodges (1954 to 1961) played a critical role in getting the universities to identify what specific university-based research and workforce assets might be attractive to industry. Governor Sanford (1961 to 1965) and other key leaders then followed up with a committed effort to attract the first big R&D-intensive companies to the region, such as IBM and the National Institute for Environmental Health Sciences. Burroughs Wellcome (now GlaxoSmithKline) located to RTP in 1971. North Carolina's vision for diversification centered on both information technology (IT) and biotechnology. In 1984, North Carolina established the North Carolina Biotech Center (NCBiotech) as a state-funded, private, nonprofit organization. Its mission is to "accelerate life sciences technology-based economic development through innovation, commercialization, education, and business growth." Life sciences includes both human health and agricultural biotech.

NCBiotech is a 501c3 nonprofit organization with an annual operating budget of approximately $18 million. Currently, approximately $13.6 million comes from the state and the Center's remaining revenue comes from federal grants, consulting, and conferences held at NCBiotech's conference center.

Functionally, NCBiotech is organized along five business lines: (1) grants to support translational research at North Carolina universities, (2) loans to early-stage, pre-revenue companies, (3) economic development providing state and regional economic development partners with due diligence and help in formulating strategy for recruitment and attraction, (4) research on a contract basis for companies and other organizations, and (5) a conference center. NCBiotech has 64 staff. Seven of these staff members are located across NCBiotech's five regional offices in Asheville, Charlotte, Winston-Salem, Greenville, and Wilmington.

[19] Ibid.

Timeline of Key Events in North Carolina's Life Sciences Sector Development

1950s: North Carolina manufacturing base built on tobacco, furniture, and textiles

1959: Establishment of Research Triangle Park, which struggled for the first 6 years

1960s–1980s: Traditional manufacturing in decline

1980s: Focus on biotechnology because of its potential to generate clean, safe, high-paying manufacturing jobs and jobs that can be located in more rural parts of the state

1984: Major investments in NC Biotech Center to support:

- Discovery: Strengthen NC academic and industrial biotech research capabilities
- Manufacturing: Enhance the teaching and workforce training capabilities of NC universities and community college system
- Economic Development Diffusion: Use incentives to drive supply chain investments in rural parts of the state

2003: $64 million investment in Biomanufacturing Training & Education Center at NCSU and statewide training via other colleges and community colleges

NCBiotech's value to the state's life sciences economic development activities stems from the subject matter expertise of its staff—understanding the nuances of the industry, being able to provide economic development partners with a clinical assessment of a pre-revenue company, and being positioned to effectively pitch the state as a result of its knowledge of university technical strengths from NCBiotech grants activities and startup activities from its loan program.

Appendices

Appendix A. Tables and Figures

Table A-1. Tennessee vs. U.S. Life Sciences Industry Performance, 2010–2016

Industry Subsector	Tennessee			United States			TN Industry Share/U.S.*
	2010	2016	2010–16 % Change	2010	2016	2010–16 % Change	2016
Bioscience Distribution							
Establishments	784	871	11%	36,170	39,149	8%	2.2%
Employment	15,467	13,739	−11%	440,394	469,640	7%	2.9%
Location Quotient	1.76	1.43					
Average Annual Salary	$72,446	$83,527	15%	$80,049	$93,677	17%	($10,150)
Medical Devices and Equipment							
Establishments	102	138	35%	6,957	8,083	16%	1.7%
Employment	8,151	8,541	5%	343,468	359,293	5%	2.4%
Location Quotient	1.19	1.16					
Average Annual Salary	$71,944	$87,620	22%	$72,301	$84,746	17%	$2,874
Research, Testing, and Medical Labs							
Establishments	276	467	69%	22,212	33,007	49%	1.4%
Employment	8,254	8,014	−3%	451,923	547,566	21%	1.5%
Location Quotient	0.91	0.71					
Average Annual Salary	$73,192	$73,396	0%	$84,065	$106,942	27%	($33,546)
Drugs and Pharmaceuticals							
Establishments	33	48	45%	2,908	3,754	29%	1.3%
Employment	3,052	2,339	−23%	296,759	299,113	1%	0.8%
Location Quotient	0.51	0.38					
Average Annual Salary	$89,463	$82,145	−8%	$99,486	$113,815	14%	($31,670)
Total Bioscience Industry							
Establishments	1,095	1,524	39%	68,246	83,993	23%	1.8%

Employment	34,923	32,633	−7%	1,532,545	1,675,612	9%	1.9%
Location Quotient	1.09	0.92					
Average Annual Wage	$76,761	$81,672	6%	$83,975	$99,795	19%	($18,123)
Total Private Sector							
Establishments	135,620	148,812	10%	8,752,494	9,243,034	6%	1.6%
Employment	2,138,027	2,478,830	16%	106,863,403	120,884,570	13%	2.1%
Average Annual Wage	$41,759	$47,618	14%	$46,317	$53,354	15%	($5,736)

Note: *Read ($31,670) as "TN's average annual salary in Drugs and Pharmaceuticals in 2016 was $31,670 lower than the U.S. industry average."
Source: Battelle/BIO and TEConomy/BIO. 2010 and 2018. *State Bioscience Industry* reports.

Table A-2. Bioscience NAICS Included in the Data

Bioscience Subsector	NAICS Code	NAICS Description
Drugs & Pharmaceuticals		
	325411	Medicinal and Botanical Manufacturing
	325412	Pharmaceutical Preparation Manufacturing
	325413	In-Vitro Diagnostic Substance Manufacturing
	325414	Biological Product (except Diagnostic) Manufacturing
Medical Devices & Equipment		
	334510	Electromedical and Electrotherapeutic Apparatus Manufacturing
	334516	Analytical Laboratory Instrument Manufacturing
	334517	Irradiation Apparatus Manufacturing
	339112	Surgical and Medical Instrument Manufacturing
	339113	Surgical Appliance and Supplies Manufacturing
	339114	Dental Equipment and Supplies Manufacturing
Research, Testing, & Medical Laboratories		
	541380*	Testing Laboratories
	541711	Research and Development in Biotechnology
	541712*	Research and Development in the Physical, Engineering and Life Sciences (except Biotechnology)
	621511	Medical Laboratories
Bioscience-Related Distribution†		
	423450	Medical, Dental and Hospital Equipment and Supplies Merchant Wholesalers
	424210*	Drugs and Druggists' Sundries Merchant Wholesalers
	424910*	Farm Supplies Merchant Wholesalers

Notes:

*Includes only the portion of these industries engaged in relevant life sciences activities.

†Bioscience-related distribution employment data discussed in this analysis are not exact because we included agricultural distribution and did not include FedEx.

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* reports.

Table A-3. Life Sciences Sectors: 2016 State Employment Rankings

2016 Employment Rank	Bioscience Distribution	Medical Devices and Equipment	Research, Testing, and Medical Labs	Drugs and Pharmaceuticals
1	California	California*	California*	California*
	57,076	62,686	94,348	50,456
2	Texas	Minnesota*	Massachusetts*	New Jersey*
	38,181	27,555	51,202	22,846
3	Florida*	Massachusetts*	New Jersey*	North Carolina*
	36,155	21,378	35,600	20,656
4	Illinois*	Indiana	Pennsylvania*	Illinois*
	26,058	17,317	29,588	20,102
5	New Jersey	Florida	North Carolina*	New York
	22,015	16,437	28,896	19,504
6	New York	Pennsylvania	New York	Pennsylvania*
	19,192	16,239	26,737	17,885
7	Ohio	Puerto Rico	Florida	Indiana*
	19,114	12,956	24,168	17,862
8	Pennsylvania	Illinois	Texas	Puerto Rico
	16,549	12,950	23,993	14,207
9	North Carolina	New Jersey	Maryland	Texas
	15,287	12,832	20,194	11,652
10	Georgia	New York	Illinois	Massachusetts
	14,306	12,661	17,572	10,895
Tennessee	**13,739 *(Ranks 11)***	**8,541 *(Ranks 16)***	**8,014**	**2,339**

Note: * Indicates a state is large and specialized (location quotient equal to 1.20 or higher) in that industry segment.

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* reports.

Table A-4. Biosciences Distribution Employment Ranking: Tennessee vs. Top 10 States, 2016

State	Rank	Establishments	Employment	Location Quotient	Share of U.S. Employment
California	1	3,858	57,076	1.04	12.2%
Texas	2	2,969	38,181	0.99	8.1%
Florida	3	3,018	36,155	1.28	7.7%
Illinois	4	1,881	26,058	1.31	5.5%
New Jersey	5	1,237	22,015	1.69	4.7%
New York	6	1,573	19,192	0.64	4.1%
Ohio	7	1,548	19,114	1.07	4.1%
Pennsylvania	8	777	16,549	0.84	3.5%
North Carolina	9	1,615	15,287	1.10	3.3%
Georgia	10	1,060	14,306	1.02	3.0%
Tennessee	**11**	**871**	**13,739**	**1.43**	**2.9%**

Source: Battelle/BIO and TEConomy/BIO. multiple years. *State Bioscience Industry* reports.

Table A-5. Medical Devices and Equipment Employment Ranking: Tennessee vs. Top 15 States, 2016

State	Rank	Establishments	Employment	Location Quotient	Share of U.S. Employment
California	1	1,183	62,686	1.49	17.4%
Minnesota	2	343	27,555	3.80	7.7%
Massachusetts	3	288	21,378	2.35	6.0%
Indiana	4	155	17,317	2.25	4.8%
Florida	5	662	16,437	0.76	4.6%
Pennsylvania	6	277	16,239	1.08	4.5%
Puerto Rico	7	55	12,956	6.51	3.6%
Illinois	8	550	12,950	0.85	3.6%
New Jersey	9	300	12,832	1.28	3.6%
New York	10	363	12,661	0.55	3.5%
Michigan	11	299	11,643	1.07	3.2%
Texas	12	434	10,859	0.37	3.0%
Colorado	13	168	9,993	1.57	2.8%
Wisconsin	14	177	9,941	1.37	2.8%
Ohio	15	191	9,232	0.67	2.6%
Tennessee	**16**	**138**	**8,541**	**1.16**	**2.4%**

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* report.

Table A-6. Medical Devices and Equipment Employment Ranking: Memphis MSA vs. Top 15 MSAs, 2016

Rank	Metropolitan Statistical Area	2016 Employment
1	Los Angeles-Long Beach-Anaheim, CA	27,935
2	Minneapolis-St. Paul-Bloomington, MN-WI	26,440
3	Boston-Cambridge-Newton, MA-NH	16,567
4	New York-Newark-Jersey City, NY-NJ-PA	15,954
5	Chicago-Naperville-Elgin, IL-IN-WI	12,391
6	Salt Lake City, UT	8,948
7	San Francisco-Oakland-Hayward, CA	8,841
8	San Diego-Carlsbad, CA	8,668
9	San Jose-Sunnyvale-Santa Clara, CA	7,621
10	Milwaukee-Waukesha-West Allis, WI	6,199
11	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	6,019
12	**Memphis, TN-MS-AR**	**5,876**
13	Pittsburgh, PA	5,072
14	Seattle-Tacoma-Bellevue, WA	4,722
15	Denver-Aurora-Lakewood, CO	4,645

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* report.

Note: Medical device employment data for Warsaw, IN, are not available because the city is too small and industry-level data are suppressed to protect company confidentiality.

Table A-7. Tennessee Academic R&D Expenditures: National Rank and Expenditures by Field, FY 2018 ($M)

U.S. Rank	Institution	Total	Life Sciences	Engineering	Physical Sciences	Sciences, nec	Computer and Information Sciences	All Other
31	Vanderbilt U. and Vanderbilt U. Medical Center	738,620	560,124	87,250	29,053	21,796	199	40,198
90	U. Tennessee, Knoxville	259,607	23,092	128,675	24,307	17,417	14,367	51,749
168	U. Tennessee, Health Science Center	79,460	78,204	598	0	658	0	0
174	U. Tennessee, Knoxville, Institute of Agriculture	70,305	59,827	5,643	0	4,776	0	59
178	U. Memphis	64,297	11,041	9,806	1,883	192	13,831	27,544
279	Tennessee State U.	17,681	13,330	1,467	481	0	480	1,923
306	East Tennessee State U.	14,043	9,373	0	425	0	0	4,245
316	Tennessee Technological U.	12,765	1,202	7,301	1,491	1	2,096	675
364	U. Tennessee, Chattanooga	7,585	776	1,674	10	2,579	506	2,040
484	Fisk U.	2,790	2,162	0	197	0	225	206

State Total	**1,293,909**	**778,534**	**242,954**	**58,574**	**25,662**	**31,791**	**156,394**

Source: National Science Foundation. 2019. National Center for Science and Engineering Statistics, Higher Education R&D Survey, FY2018.

Table A-8. North Carolina Academic R&D Expenditures: National Rank and Expenditures by Field, FY 2018 ($M)

U.S. Rank	Institution	Total	Life Sciences	Engineering	Physical Sciences	Sciences, nec	Computer and Information Sciences	All Other
10	Duke U.	1,126,925	950,245	80,554	19,322	0	5,785	71,019
12	U. North Carolina, Chapel Hill	1,102,063	798,649	29,932	35,118	232	18,483	219,649
47	North Carolina State U.	500,445	234,319	158,389	21,204	13,842	11,537	61,154
117	Wake Forest U.	191,371	188,702	49	1,755	0	159	706
216	East Carolina U.	39,074	26,176	1,276	1,464	0	266	9,892
220	North Carolina Agricultural & Technical State U.	38,140	17,349	13,123	1,808	104	1,686	4,070
	State Total	**3,205,161**	**2,294,048**	**318,548**	**95,913**	**14,904**	**49,527**	**432,221**

Source: National Science Foundation. 2019. National Center for Science and Engineering Statistics, Higher Education R&D Survey, FY2018.

Table A-9. Vanderbilt University: Licensing to Tennessee Life Sciences Startups by Technology Sector, 2012–2019

Company	Technology	Year
Microarrays, Inc.	Laboratory/R&D Services	N/A
WaveFront Biosciences	R&D Tools	2012
Amytrx Therapeutics	Pharmaceuticals	2014
Mirah, Inc.	Digital IT	2015
nPhase	Digital IT	2015
Pendant Biosciences	Drug Delivery	2015
VolumMetrix	Medical/Surgical Devices	2015
Metalytics, LLC	Laboratory/R&D Services	2016
Protypia, LLC	Contract Research for Drug Discovery	2016
Virtuoso Surgical, Inc.	Medical/Surgical Devices	2016
Abvance Therapeutics, Inc.	Pharmaceuticals	2017
Appello Therapeutics	Pharmaceuticals	2017
Path Ex, Inc.	Medical/Surgical Device	2017
Nashville Biosciences	Laboratory/R&D Services	2018
Synchromotion, LLC	Medical/Surgical Devices	2019
Unify Pharmaceuticals Corp	Pharmaceuticals	2019
IDBiologics, Inc.	Biologics	2019
Cumberland Emerging Technologies*	Pharmaceuticals	Multiple

Note: *Vanderbilt University's licensing activity to Cumberland Emerging Technologies is on-going.

Source: Vanderbilt University Center for Technology Transfer and Commercialization

Table A-10. University of Tennessee Research Foundation: 10 Years Licensing to Tennessee Life Sciences Startups by Technology Sector, 2010–2019

Company	Technology	Year
Hubble Telemedical	Medical Device	2010
Solex	Biotechnology	2011
Nanophthalmics	Medical Device	2012
Entac Medical	Medical Device	2012
Infusense	Medical Device	2012
490 Biotech	Biotechnology	2012
HandMinder	Medical Device	2012
E-Vision Technologies	Medical Device	2013
Floodlight Genomics	Biotechnology	2014
Ipax Pharmaceuticals	Pharmaceuticals	2015
PreTel Health	Medical Device	2015
EMBrace	Medical Device	2017
Vortex Biotechnology	Diagnostics	2017
Oculo Therapy	Pharmaceuticals	2018
Minerva Discovery	Pharmaceuticals	2018
SEAK Therapeutics	Pharmaceuticals	2019
Azimuth Sleep Solutions	Medical Device	2019

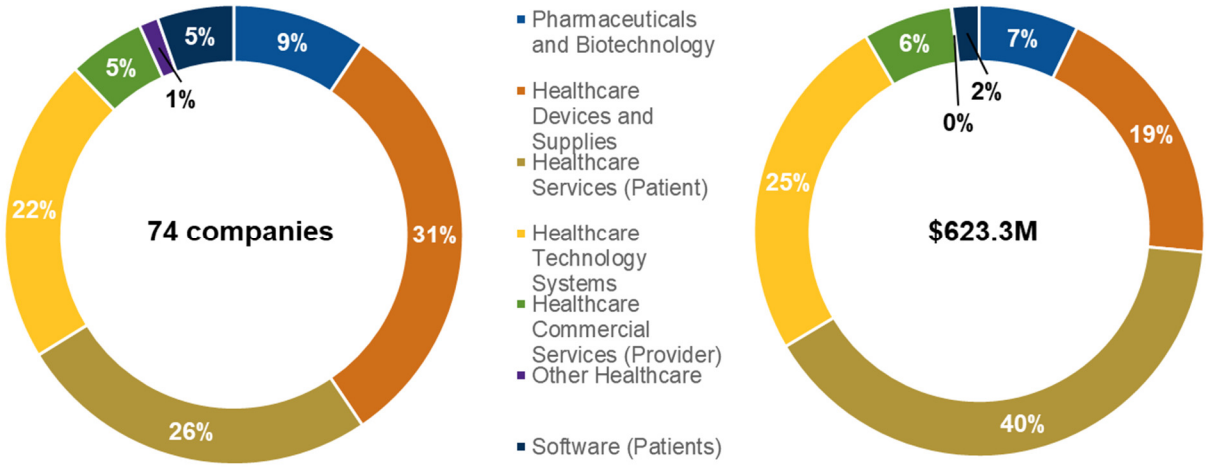
Source: University of Tennessee Research Foundation

Table A-11. Tennessee Life Sciences Startups That Received LaunchTN SBIR/STTR Matching Fund Grant, 2019

Match-Awarded Company	Phase Funded	Awarding Agency	SBIR Award Value	Project	Source of Intellectual Property
490 Biotech Inc.	Phase I	NIH	$150,000	Non-invasive brain cell imaging	University of Tennessee–Knoxville
Adaptive Technology Consulting	Phase I	NIH	$224,978	E-health solution for autism identification	Vanderbilt University
Cumberland Pharmaceuticals	Phase II	NIH	$924,071	DNA damage response pathways for the treatment of advanced lung cancer	Cumberland Pharmaceuticals
Curie Co. Inc.	Phase I	NIH	$225,000	An enzyme immobilization platform for the production of biopharmaceuticals	Curie Co.
HeroWear, LLC	Phase I	NSF	$225,000	Mechanized clothing for low back support	Vanderbilt University
IQuity Labs, Inc.	Phase II	NIH	$498,258	Test to distinguish fibromyalgia syndrome from rheumatic diseases	IQuity
Oculo Therapy	Phase I	NIH	$225,000	Extended release formulation of a new IOP lowering drug for improved treatment of glaucoma	University of Tennessee Health Sciences Center
PreTel Health	Phase I	NIH	$149,231	EMG-based fetal monitor to identify true preterm labor	University of Tennessee Health Sciences Center
Volumetrix, LLC	Phase I	NIH	$176,229	Non-Invasive Venous Waveform Analysis (NIVA) in patients with Heart Failure	Vanderbilt University

Sources: LaunchTN (2019), "Making It to Market," Medium, 19 November 2019, https://medium.com/@LaunchTN/making-it-to-market-2a03c062b9f8 and SBIR/STTR Awards Database for details about SBIR award value. Seven life sciences companies were among the 28 companies that received $3 million in LaunchTN SBIR/STTR Matching Program funds.

Table A-12. Venture Capital Raised by Healthcare Sector: Share of Companies and Share of Investment, 2014-2018



Source: Pitchbook Venture Capital, Private Equity, and M&A Database.

Table A-13. Tennessee Life Sciences/Healthcare Venture Capital Activity by Sector, 2014–2018

Industry Sector Group	Number of Companies	Number of Deals	Total Invested ($M)
Healthcare Services (Patient)	19	43	$248.9
Healthcare Technology Systems	16	41	$156.7
Healthcare Devices and Supplies	23	65	$120.7
Pharmaceuticals and Biotechnology	7	16	$44.6
Healthcare Commercial Services (Provider)	4	5	$40.0
Software (Patients)	4	9	$12.1
Other Healthcare	1	1	$0.3
Total	**74**	**180**	**$623.3**

Source: Pitchbook Venture Capital, Private Equity, and M&A Database.

Table A-14. Tennessee Life Sciences Venture Capital Activity by Sector, 2004–2008

Industry Sector Group	Number of Companies	Number of Deals	Total Invested ($M)
Healthcare Devices and Supplies	7	10	$36.96
Healthcare Technology Systems	5	6	$7.41
Healthcare Services (Patient)	1	1	$6.55
Pharmaceuticals and Biotechnology	1	2	$1.50
Total	**14**	**19**	**$52.42**

Source: Pitchbook Venture Capital, Private Equity, and M&A Database.

Table A-15. Total Life Sciences Venture Capital Investment Rankings by State, 2014–2017

Rank	State	Total VC ($M)
1	California	$28,440.8
2	Massachusetts	$15,197.6
3	New York	$2,157.7
4	Washington	$1,945.6
5	Pennsylvania	$1,731.4
6	Texas	$1,590.5
7	Illinois	$1,473.1
8	North Carolina	$1,488.3
9	Minnesota	$1,130.6
10	New Jersey	$1,098.8
11	Colorado	$1,054.6
12	Maryland	$921.0
13	Connecticut	$897.3
14	Florida	$890.3
15	Ohio	$804.0
16	Georgia	$691.6
17	Utah	$620.1
18	Michigan	$576.3
19	Missouri	$317.1
20	Virginia	$304.9
21	Wisconsin	$296.6
22	Arizona	$293.0
23	**Tennessee**	**$290.0**
24	Indiana	$241.3

Note: These totals do not include agricultural bioscience VC investments, such as investments in agricultural chemicals and biofuels, but they do include biotechnology, which may include companies focused on agricultural biotech applications.

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* reports.

Table A-16. Total Biosciences-Related Patent Rankings by State, 2014–2017

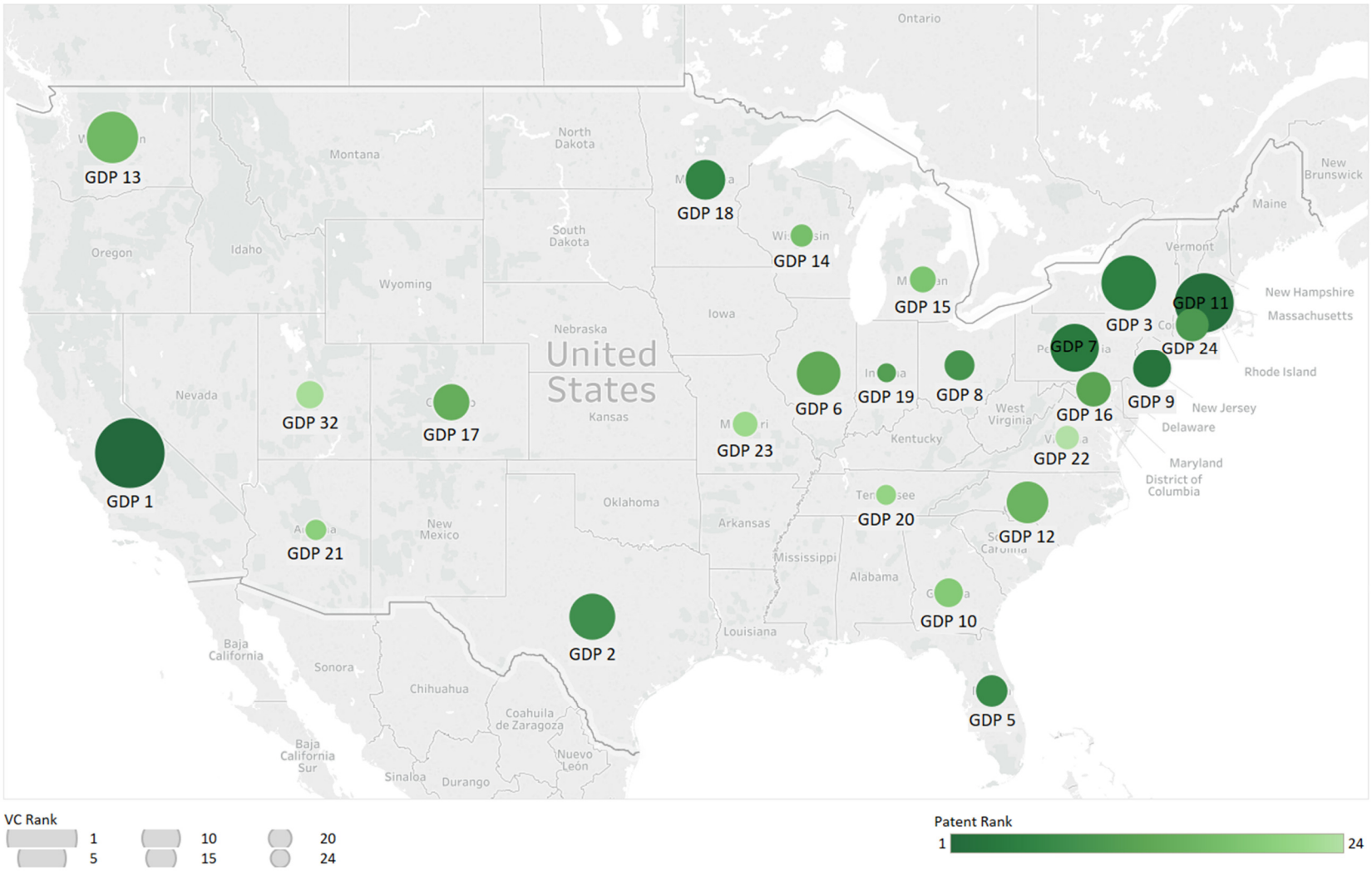
Rank	State	Total Patents	Average Patents Per Year
1	California	28,359	7,090
2	Massachusetts	11,079	2,770
3	New Jersey	6,936	1,734
4	Pennsylvania	6,512	1,628
5	New York	6,507	1,627
6	Minnesota	6,076	1,519
7	Florida	4,580	1,145
8	Texas	4,363	1,091
9	Ohio	4,113	1,028
10	Connecticut	3,387	847
11	Indiana	3,361	840
12	Maryland	3,348	837
13	Illinois	3,338	835
14	Colorado	3,070	768
15	North Carolina	2,846	712
16	Washington	2,826	707
17	Wisconsin	2,186	547
18	Michigan	2,147	537
19	Georgia	1,892	473
20	Arizona	1,818	455
21	**Tennessee**	**1,686**	**422**

Note: These totals do not include agricultural bioscience patents for agricultural chemicals, biological sampling and analysis, or novel plant variants, but do include microbiology and enzymes, which may have some agricultural applications.

Patent classes included Biochemistry, Bioinformatics and Health IT, Drugs and Pharmaceuticals, Medical and Surgical Devices, and Microbiology and Genetics.

Source: Battelle/BIO and TEConomy/BIO. 2018. *State Bioscience Industry* reports.

Table A-17. Comparing Life Sciences Venture Capital Investment, Life Sciences Patenting, and GDP Ranks Across the United States, 2014–2017



Note: The size of the circle indicates the amount of VC investment attracted from 2014 through 2017 and national rank. The shade of green indicates the number of biosciences-related patents awarded from 2014 through 2017 and national rank. The label "GDP #" indicates national GDP ranking in 2017. Tennessee ranked 20th in GDP, 21st for biosciences-related patents, and 23rd for life sciences VC investment.

Table A-18. Top 20 Assignee Organizations: All Bioscience Patents Awarded to Tennessee Inventors, 2014–2018

Assignee Organization	Patents Granted 2014-2018	Average Patents Per Year
Warsaw Orthopedic, Inc.	569	114
Individual Inventors	272	54
Vanderbilt University	250	50
Smith & Nephew, Inc.	201	40
University of Tennessee Research Foundation	84	17
St. Jude Children's Research Hospital	82	16
Eastman Chemical Company	79	16
UT-Battelle, LLC	79	16
International Business Machines Corporation	79	16
FedEx Corporate Services, Inc.	79	16
Wright Medical Technology, Inc.	76	15
Siemens Aktiengesellschaft	41	8
GTX, Inc.	35	7
Microport Orthopedics Holdings Inc.	33	7
Gyrus ACMI, Inc.	28	6
Zimmer, Inc.	27	5
NuSirt Sciences, Inc.	20	4
BioDlogics, LLC	20	4
Pioneer Hi-Bred International, Inc.	19	4
Cumberland Pharmaceuticals	18	4

Note: RTI analysis based on patents in which one or more inventors have a Tennessee address.

Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Table A-19. Top 20 Assignee Organizations: All Bioscience Patents Awarded to North Carolina Inventors, 2014–2018

Assignee Organization	Patents Granted 2014–2018	Average Patents Per Year
International Business Machines Corporation	1,849	370
Lenovo Enterprise Solutions PTE. LTD.	558	112
Bank of America Corporation	421	84
Individual Inventors	254	51
Red Hat, Inc.	220	44
Duke University	214	43
EMC Corporation	173	35
SAS Institute Inc.	163	33
The University of North Carolina at Chapel Hill	121	24
Wake Forest University Health Sciences	116	23
NetApp, Inc.	109	22
QUALCOMM Incorporated	105	21
Cook Medical Technologies LLC	93	19
NVIDIA Corporation	78	16
Syngenta Participations AG	47	9
Cisco Technology, Inc.	47	9
Empire Technology Development LLC	39	8
North Carolina State University	34	7
Hand Held Products, Inc.	34	7
Bioptigen, Inc.	34	7

Note: RTI analysis based on patents in which one or more inventors have a North Carolina address.

Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Table A-20. Top Assignee Organizations: Health Informatics Awarded to Tennessee Inventors, 2011–2018

Assignee Organization	Patents Granted 2011–2018	Average Patents Per Year
Individual inventors	111	14
International Business Machines Corporation	91	11
FedEx	61	8
United States Postal Service	30	4
Oak Ridge National Laboratory (UT-Battelle, LLC)	25	3
Google Inc.	18	2
University of Tennessee Research Foundation	13	2
Smith & Nephew, Inc.	12	1
Digital Reasoning Systems, Inc.	12	1
Zimmer, Inc.	10	1
HCA Holdings, Inc.	10	1

Note: RTI analysis based on patents in which one or more inventors have a Tennessee address.

Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Table A-21. Top Assignee Organizations Biochemistry Patents Awarded to Tennessee Inventors, 2011–2018

Assignee Organization	Patents Granted 2011–2018	Average Patents Per Year
Vanderbilt University	114	14
Eastman Chemical Company	52	7
University of Tennessee Research Foundation	31	4
St. Jude Children's Research Hospital	30	4
Medtronic (Warsaw Orthopaedic, Inc., Medtronic Vascular)	21	3
GTX, Inc. (Memphis)	17	2
Oak Ridge National Laboratory (UT-Battelle, LLC)	12	1
Individual inventors	11	1
Merck Sharp & Dohme Corp.	10	1

Note: RTI analysis based on patents in which one or more inventors have a Tennessee address.

Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

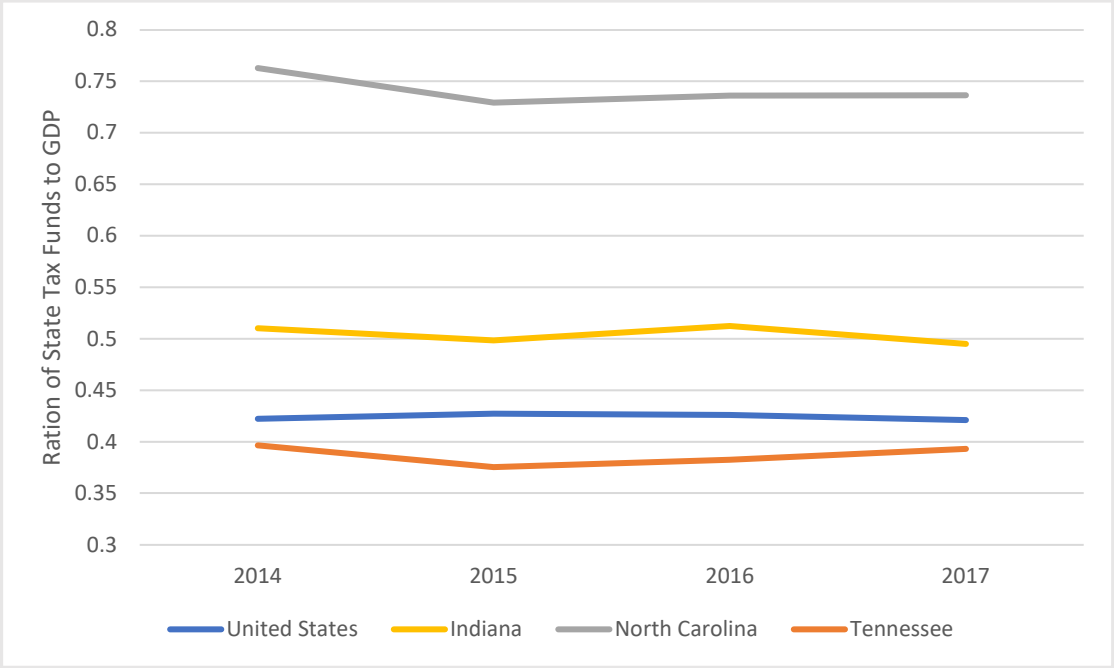
Table A-22. Top Assignee Organizations: Genetics Patents Awarded to Tennessee Inventors, 2011–2018

Assignee Organization	Patents Granted 2011–2018	Average Patents Per Year
Oak Ridge National Laboratory (UT-Battelle, LLC)	34	4
Vanderbilt University	30	4
St. Jude Children's Research Hospital	28	4
Pioneer Hi-Bred International, Inc.	20	3
University of Tennessee Research Foundation	15	2
Medtronic (Warsaw Orthopaedic, Inc., Medtronic Vascular)	11	1

Note: RTI analysis based on patents in which one or more inventors have a Tennessee address.

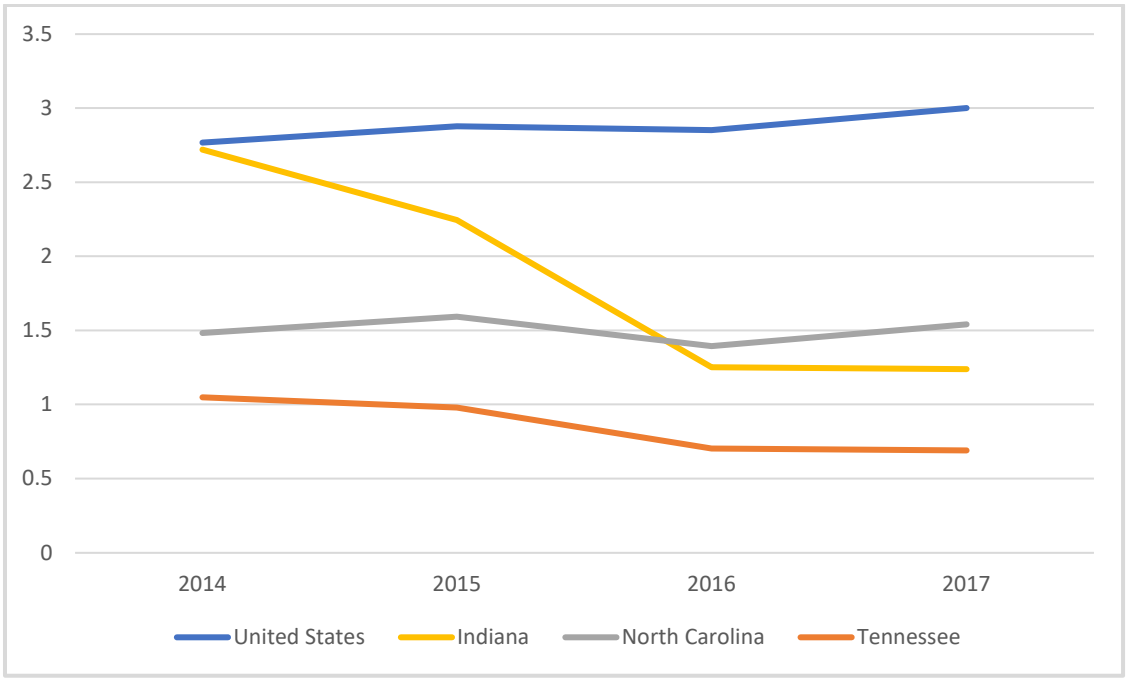
Source: U.S. Patent and Trademark Office. PatentsView. 2019. Accessed 11/1/2019 at https://www.patentsview.org/

Table A-23. Appropriations of State Tax Funds for Higher Education as a Percentage of Gross Domestic Product, 2014–18



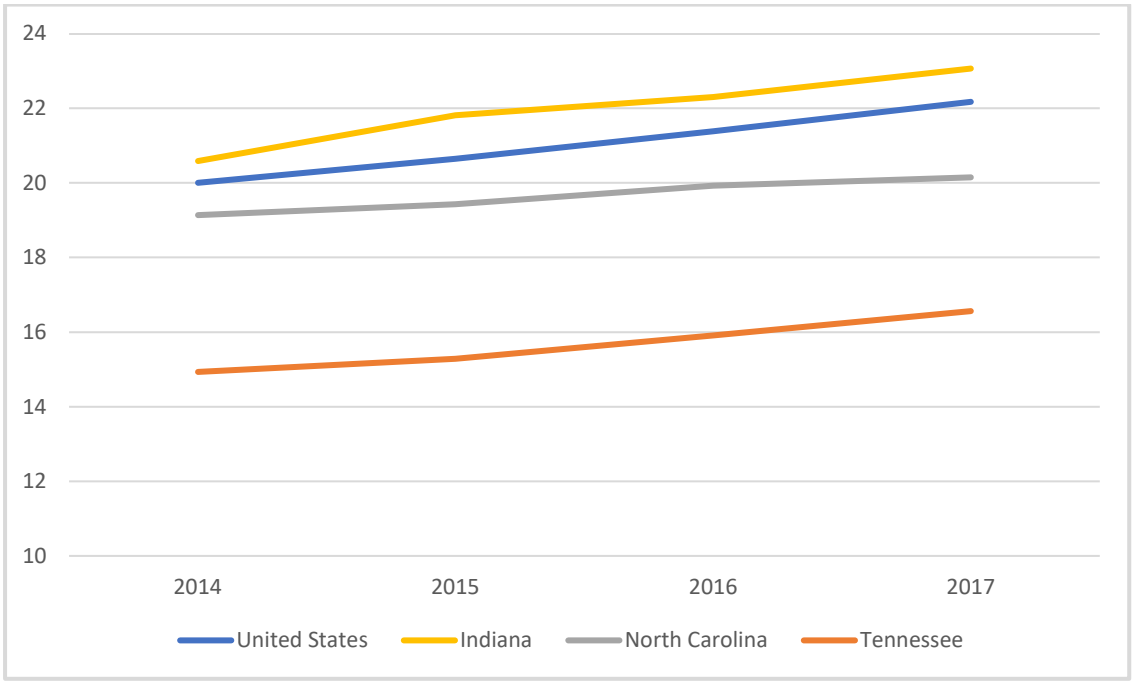
Source: National Science Foundation. National Science Board. 2018 Science & Engineering State Indicators.

Table A-24. Associate's Degrees in Science and Engineering Conferred per 1,000 Individuals 18–24 Years Old, 2014–17



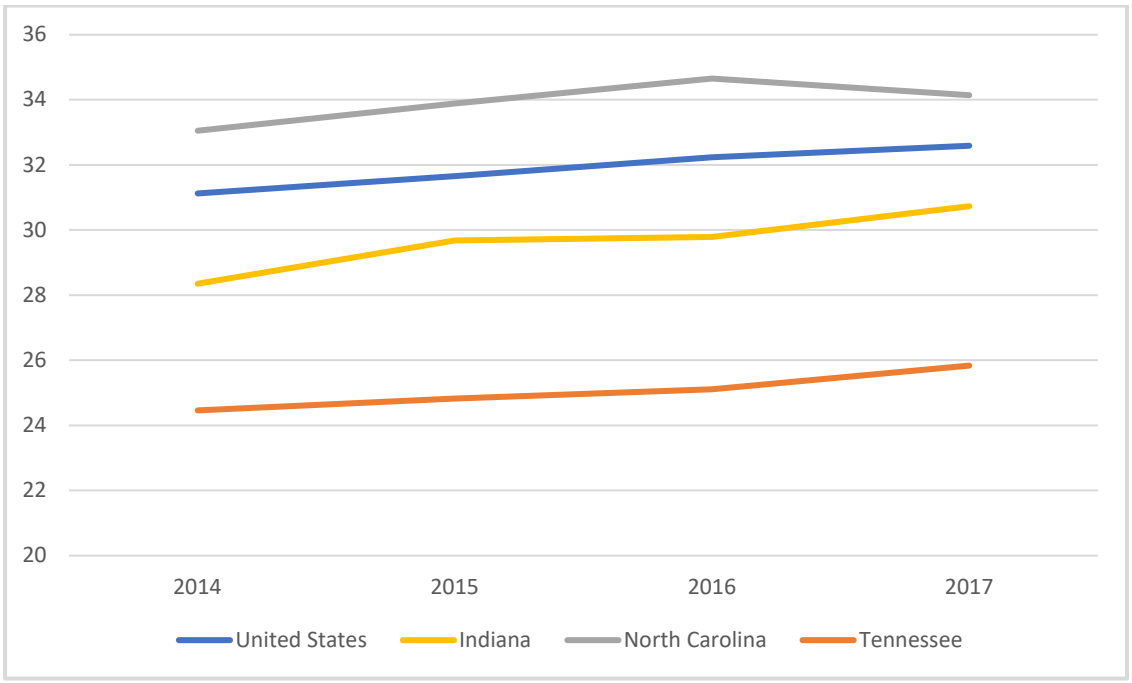
Source: National Science Foundation. National Science Board. 2018 Science & Engineering State Indicators.

Table A-25. Bachelor's Degrees in Science and Engineering Conferred per 1,000 Individuals 18-24 Years Old, 2014-17



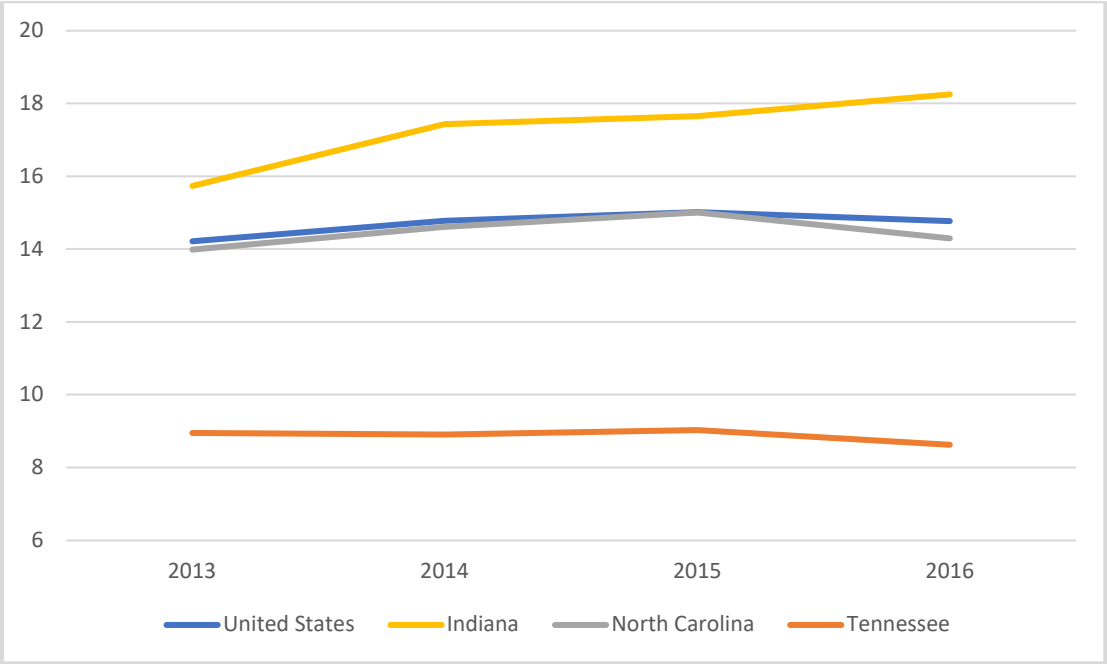
Source: National Science Foundation. National Science Board. 2018 Science & Engineering State Indicators.

Table A-26. Science and Engineering Degrees as a Percentage of Higher Education Degrees Conferred, 2014-17



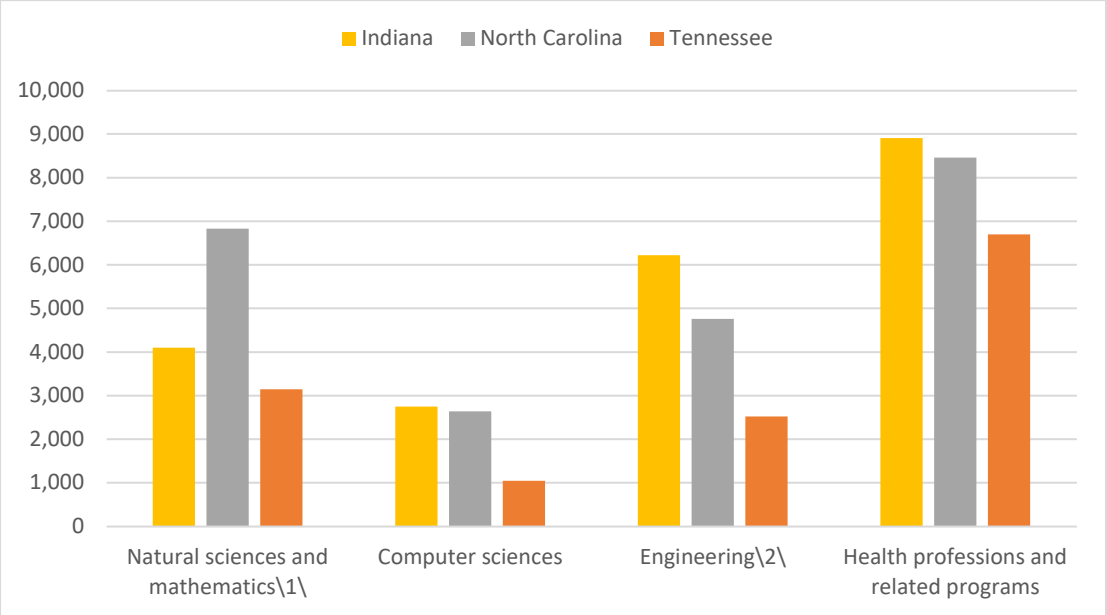
Source: National Science Foundation. National Science Board. 2018 Science & Engineering State Indicators.

Table A-27. Science, Engineering, and Health Graduate Students per 1,000 Individuals 25-34 Years Old, 2013-16



Source: National Science Foundation National Science Board. 2018 Science & Engineering State Indicators.

Table A-28. Degrees Conferred by Postsecondary Institutions by Field of Study, 2016-2017



Note: 1) Natural science and mathematics includes biological and biomedical sciences, physical sciences, science technologies/technicians, and mathematics and statistics. 2) Engineering includes engineering, engineering technologies/technicians, mechanic and repair technologies/technicians, and construction trades. 3) Data are for postsecondary institutions participating in Title IV federal financial aid programs. This table includes only those jurisdictions with 4-year institutions.

Source: U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Fall 2017, Completions component.

Appendix B. List of Stakeholders Interviewed

In alphabetical order by company/organization.

Name	Title	Company/Organization
Memphis		
Jodie Gilmore	Global Orthopedic Business Director and Co-Chair	Elos Medtech and Greater Memphis Medical Device Council
Leslie Smith	President and CEO	EpiCenter Memphis
Roy Smith	Executive Director	Greater Memphis Medical Device Council
Jan Bouten	Partner	Innova Memphis (Venture Capital Firm)
Gary Stevenson	Managing Partner	MB Venture Partners (Venture Capital Firm)
Stan McKee	Sr. Engineering Manager of Advanced Manufacturing and Engineering Technologies	Medtronic Spine & Biologics
Tommy Carls	Former Vice President of R&D and Memphis Research Consortium (retired Jan. 1, 2020)	Medtronic Spine & Biologics
Richard Lunsford	Senior Director of Manufacturing	MicroPort Orthopedics
Gene Baker	Vice President of Global Warehousing, Distribution, and Trade Compliance and Chair	Smith & Nephew and Greater Memphis Medical Device Council
Scott Elmer	Director, Office of Technology Licensing	St. Jude's Children's Research Hospital
Gary Bowlin	Director, Tissue Engineering and Regeneration Laboratory	University of Memphis
Jasbir Dhaliwal	Executive Vice President for Research and Innovation	University of Memphis
Ted Townsend	Chief Economic Development and Government Relations Officer	University of Memphis
Richard Majid	Vice President and Director of Technology Transfer	University of Tennessee Research Foundation/ University of Tennessee Health Sciences Center
Phil Ward	Senior Director of Manufacturing	Wright Medical
Nashville		
Brian Laden	President and COO	Appello Pharmaceuticals
Ed Cantwell	President and CEO	Center for Medical Interoperability
Joe Rolwing	Senior Director, Life Sciences Center	Cumberland Emerging Technologies
Jim Stefansic	Director of Corporate Development	Cumberland Emerging Technologies

Margaret Dolan	President and CEO	LaunchTN
Khrys Hatch	Capital Program Manager	LaunchTN
Abby Trotter	Executive Director and Partner	Life Sciences TN and Hall Strategies
Sam Lynch	CEO and Chairman	Lynch Biologics
Joe Cook, Jr.	Managing Director	Mountain Group Partners (Venture Capital Firm)
Joe Cook, III	Managing Director	Mountain Group Partners (Venture Capital Firm)
Rob Readnor	Managing Director	Mountain Group Partners (Venture Capital Firm)
Eric Elmquist	Co-Founder and Vice President for R&D	Pendant Biosciences
Shawn Glinter	Founder and CEO	Pendant Biosciences
Daniel Liebler	President	Protypia
Alan Bentley	Director of Technology Transfer	Vanderbilt University
Ashley Brady	Assistant Dean of Biomedical Career Engagement and Strategic Partnerships	Vanderbilt University
Jennifer Pietenpol	Executive Vice President of Research, Director for Vanderbilt-Ingram Cancer Center	Vanderbilt University Medical Center
Knoxville		
Stephen Ripp	Chief Operating Officer	490 Biotech
Eric Mayer	CEO	EDP Biotech
Marti Head	Director, Joint Institute for Biological Sciences	Oak Ridge National Laboratory
Tom Ballard	Chief Alliance Officer	PYA P.C.
Stacy Patterson	Vice President for Research, Outreach, and Economic Development	University of Knoxville
Chattanooga		
Ray Tabibiazar	Managing Director	526 Ventures, LLC (Venture Consulting)
Marcus Shaw	CEO	CO.LAB (HealthTech Accelerator)
Charlie Brock	Senior Advisor and Board Member	FourBridges Capital Partners and Pinnacle Financial Partners

David Adair	Managing Partner and Co-Founder	Solas BioVentures (Venture Capital Firm)
Joshua Eckelberry	Associate	Solas BioVentures (Venture Capital Firm)
Outside Perspectives		
Baiju Shah	Senior Fellow for Innovation Senior Advisor Entrepreneur, Board Member, former CEO	Cleveland Foundation Faster Cures Initiative BioMotiv (Pharmaceutical Accelerator)
Teresa Lynch	Principal	Mass Economics; conducting Memphis Industry Cluster Strategy
William Bullock	Senior Vice President	NC Biotech Center