A Guide to Evaluating State Bioscience Investments

Performed for:

Connecticut Innovations

Performed by:

TEConomy Partners, LLC

January 2018

TECONOMY PARTNERS LLC

Innovating Tommorow's Economic Landscape

TEConomy Partners, LLC is a global leader in research, analysis, and strategy for innovation-based economic development. Today, we're helping nations, states, regions, universities, and industries blueprint their future and translate knowledge into prosperity.

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I. Introduction

Recognizing the economic importance of the bioscience industry, many states and regions have developed initiatives designed to catalyze the growth of bioscience companies. These investments have taken many forms, from investments in academic medical centers and/or university research initiatives to large, transformative initiatives, such as California's $3 billion investment in the California Institute for Regenerative Medicine and Massachusetts' $1 billion Life Sciences Initiative. Regardless of the scale of investment, it is important to understand how these taxpayer-funded initiatives are impacting the state's economy and its citizens by analyzing, evaluating, and communicating the economic and societal return on investment.

Historically, a major facet of Connecticut's economic development efforts has been focused on the bioscience industry. The State has worked to advance this industry sector through a varied set of organizations, programs, and initiatives, including:

- Connecticut Innovations (CI), a quasi-public technology-based economic development organization that has taken the lead in advancing key programs for biosciences development, including venture investments, commercialization funding, and assisting companies with winning federal R&D grants
- BioCT, previously known as CURE, the state's bioscience industry trade organization
- The Regenerative Medicine Research Fund (RMRF), which allocates sizable funding toward stem cell research projects
- Jackson Laboratory for Genomic Medicine (JAX Genomic Medicine), in which the State invested $291 million in a partnership in personalized medicine and systems genomics
- Bioscience Connecticut, a state-funded initiative to expand the University of Connecticut Health Sciences Center in Farmington to increase research and enrollments
- Connecticut BioScience Facilities Fund, a $46 million fund managed by CI that provides financing to biotech companies for construction of wet lab and other space, and
- The Connecticut Bioscience Innovation Fund (CBIF), a $200 million 10-year fund seeking to drive innovation in the cluster.

The Connecticut State Legislature, as part of Senate Bill 962, has asked for the development of "evaluative metrics for bioscience development in the state." To address this requirement, CI has contracted with TEConomy Partners, LLC (TEConomy). The principals of TEConomy have been engaged by numerous states and region, in addition to national and international organizations, for strategic engagements in the biosciences. A common thread throughout each strategic engagement has been recommendations as well as analysis of programmatic return on investment.

Bioscience-related evaluations typically take on one of two forms:

- "Macro" level evaluations analyzing outcomes associated with industry cluster evaluations or the ultimate outcomes expected from strategic bioscience interventions, programs, or investments at the state or regional level.
- "Micro" level evaluations analyzing returns on specific program- or company-level investments or state investments into specific individual institutions.

In the narrative that follows, TEConomy identifies a framework for evaluative metrics that when analyzed will be able to evaluate the relationship between the state's investments in bioscience initiatives and the economic outcomes resulting from such investments, including, but not limited to, increased employment and resultant multiplier effects. The framework considers key metrics, such as:

- Bioscience industrial base, with an examination of detailed bioscience industry subsectors, including total growth in each bioscience subsector by employment and establishment
- R&D base, including trends in research and specific areas of strength identified by scholarly activities
- IP generation, both industrial and academic, to identify areas of research discovery progressing through technology transfer and commercialization
- Clinical trials activities
- High growth, venture-backed firm formation and growth
- Life sciences workforce development and talent generation, and
- Economic impact of direct state investments, including an analysis of the potential data requirements to be collected from funding recipients.

TEConomy Partners, LLC, (TEConomy)

TEConomy is a comprehensive, technology-based, economic development consulting group whose principals have a 25-year track record in developing strategic plans, national thought-pieces, and implementation strategies for state and local governments, universities, business development groups, industry associations, and foundations around the world. The team also sustains an intensive practice in economic analytics and regularly applies this expertise in performance of economic and functional impact analyses for government, higher education institutions, academic medical centers, industry and related associations, and other client groups. Active in both domestic and international markets, the TEConomy team has performed projects in almost every U.S. state and has performed numerous international projects.

The metrics identified are responsive to Connecticut's unique investment portfolio, but are also grounded in best practices from around the nation. The narrative provides examples from TEConomy's work with a varied set of states and national organizations. These include:

- Biennial state bioscience development reports and a translational research study conducted with the Biotechnology Innovation Organization (BIO)
- Biennial reports evaluating the impacts of the North Carolina Biotechnology Center
- Biennial tracking of progress realized as a result of the Arizona Biosciences Roadmap under the direction of the Flinn Foundation, and
- Engagements with Life Science Washington, the University of Arkansas for Medical Sciences, and Science Foundation Arizona.

The report provides details regarding recommended evaluative metrics, including the key concepts and rationale for each metric, the data source for each metric analyzed, and how collectively the recommended metrics can be utilized to evaluate the impact of the bioscience investments in the State of Connecticut.

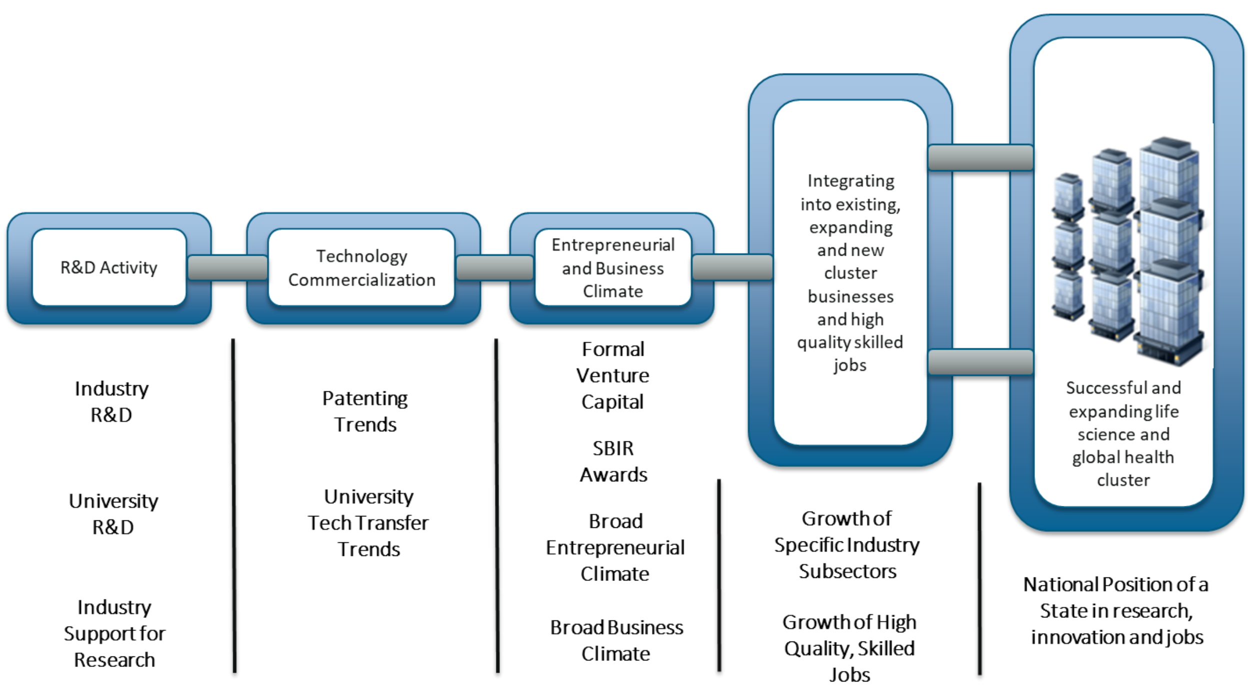
II. Evaluating State Bioscience Ecosystems at a "Macro" Level

There are two approaches to consider when examining the performance of bioscience development at a statewide, macro level—from an innovation ecosystem perspective and from a translational research perspective. The innovation ecosystem approach considers an interconnected set of components or factors that must be functioning at a high level for a vibrant and successful technology-driven industry cluster, such as the biosciences, to be successful. The translational research approach is specific to the biosciences and provides a framework for how bioscience research and development can move from ideation and conception through to successful commercial outcomes. While each approach has some overlap with the other, they both offer important insights into evaluating a state's bioscience development performance and reveal both strengths/opportunities as well as weaknesses/gaps.

Innovation Ecosystem Perspective

In considering the state-level macro impacts of investments targeted at nurturing and growing a bioscience industry cluster, a range of performance measures and metrics should be tracked. Consideration must be given to those components of a vibrant innovation ecosystem that are critical to a thriving industry cluster. In the biosciences, as in other technology-driven industry clusters, an interconnected chain of actors, ingredients, and resources must in place and functioning at a high level in order to grow the bioscience industrial base. This ecosystem and its key components to measure are presented in Figure 1.

Figure 1: Evaluating a State's Bioscience Position from an Innovation Ecosystem Perspective



Source: TEConomy Partners, LLC.

The following narrative steps through each primary component of the innovation ecosystem to present state-level, bioscience-related measures for evaluation, including the sources of these data and relevant examples.

Ecosystem Component: R&D Activity

On the "front-end" of the innovation ecosystem, a bioscience industry cluster must have access to a productive R&D base that ideally has sizable volume and strengths that span varied life sciences disciplines.[1] Leading bioscience industry clusters have strong and complementary R&D contributions from both university and industrial players. Metrics can be tracked to gauge current R&D levels, life sciences activity as a share of all R&D, and both recent and longer-term trends to track growth and emerging areas (see Table 1).

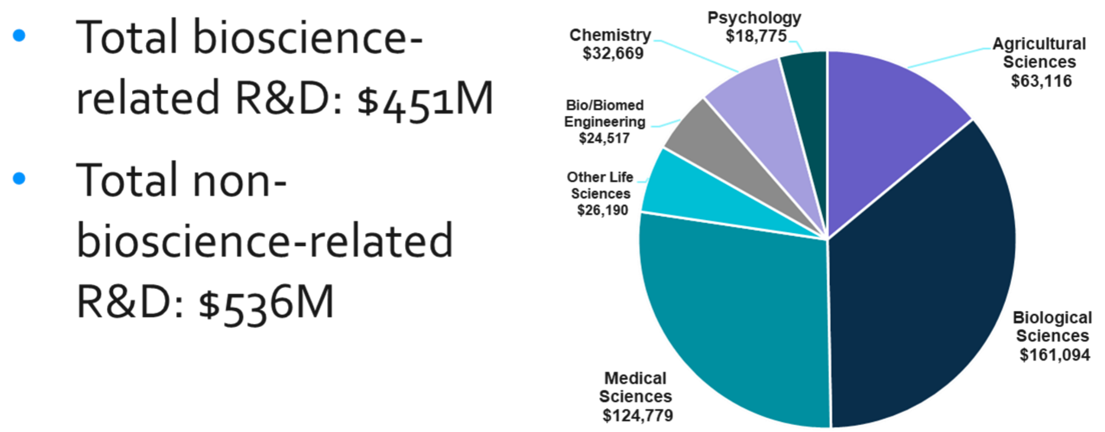
Table 1: Key Evaluation Metrics for Life Sciences R&D Activity

Ecosystem Component	Key Concepts/Definitions	Data Source
Industrial R&D	Mid-level industry detail available for: • Medical equipment & supplies • Drug & Pharmaceutical mfg.	National Science Foundation (NSF) Business R&D and Innovation Survey.
Academic R&D	Life science-related fields/disciplines: • Agricultural sciences • Bioengineering • Biological sciences • Medical sciences • Other life sciences In some cases, also include Psychology, Chemistry.	NSF Higher Education Research and Development (HERD) Survey.
Industry Support for Academic R&D	Sources of funding, including industrial, are published for each life sciences academic field	NSF Higher Education Research and Development Survey.
National Institutes of Health (NIH) Research Funding		NIH RePORTER (Research Online Reporting Tool)

Examples of analyses prepared by TEConomy for Arizona's annual tracking of progress in developing its bioscience cluster are shared in Figures 2 through 4, including both the composition and trends in university life sciences R&D.

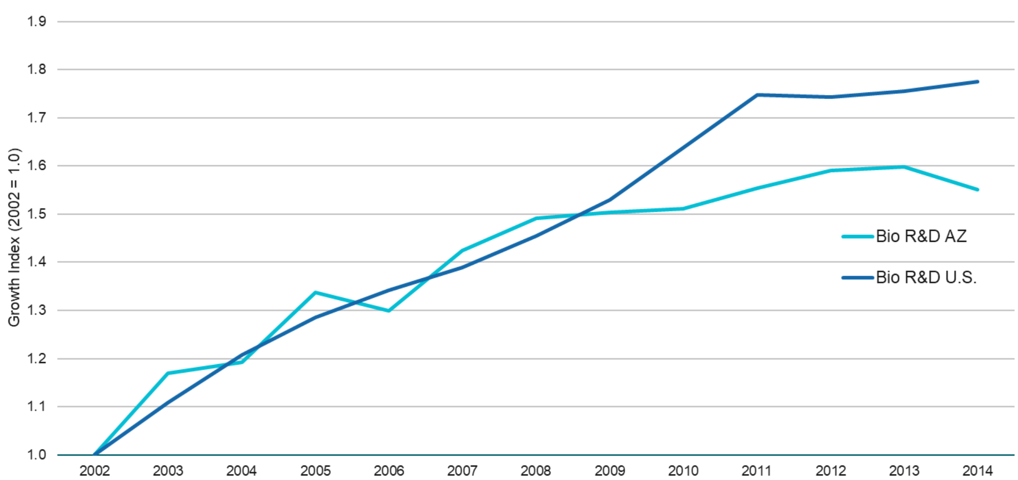
[1] In this report, as across many states and organizations, the terms "bioscience(s)" and "life sciences" are used synonymously and interchangeably.

Figure 2: Arizona's Composition of Academic R&D Expenditures in Life Science-related Fields, FY 2014



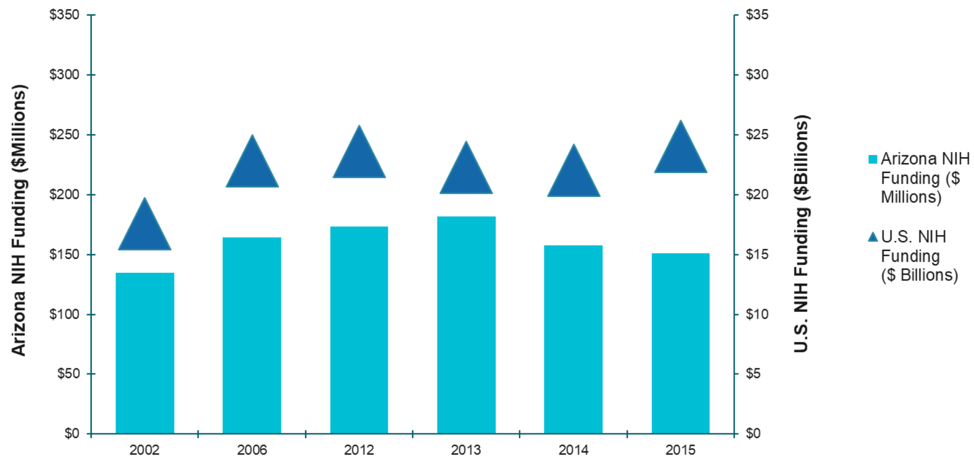
Source: TEConomy Partners, LLC analysis of NSF, HERD Survey.

Figure 3: Trends in Life Sciences Academic R&D Expenditures, Arizona and U.S., 2002-14



Source: TEConomy Partners, LLC analysis of NSF, HERD Survey.

Figure 4: Trends in NIH Funding to Arizona Institutions vs. the Nation, 2002-15



Source: TEConomy Partners, LLC analysis of NIH *RePORT* database.

Ecosystem Component: Technology Commercialization

For a state to grow its bioscience industry cluster, the innovative R&D activities of its academic institutions and companies must be translated into protected intellectual property in the form of patents and successfully commercialized new products and service offerings. Key ways in which to evaluate macro-level commercialization performance are presented in Table 2.

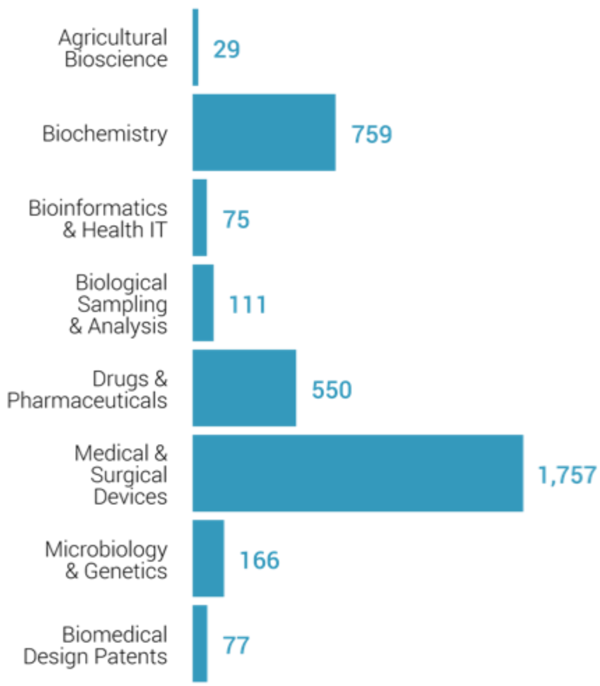
Table 2: Key Evaluation Metrics for Technology Commercialization

Ecosystem Component	Key Concepts/Definitions	Data Source
Intellectual Property: Patent Awards and Applications	TEConomy has developed detailed definition of Bioscience-related patent classes.	Clarivate Analytics' Derwent Innovation patent analysis database **Requires paid subscription*

University Technology Transfer	• Not available for bioscience-specific technologies but useful gauge of overall performance/activities.
	• Key measures include:
	  ○ Invention disclosures
	  ○ Start-ups
	  ○ Patent applications, Awards
	  ○ Licenses, options executed
	  ○ License income
	Important to *normalize* data relative to total research expenditures
		Association of University Technology Managers (AUTM) survey
		**Requires AUTM membership to access*

Patent technology classes can speak to narrow and specific areas of innovation that help to better characterize the innovation activities of broad academic fields or industrial applications. Niche strengths and regional core competencies can be gleaned from an analysis of patenting activity. For example, the TEConomy/BIO report utilizes the major areas for Connecticut illustrated in Figure 5.

Figure 5: Bioscience-related Patents Awarded to Connecticut Inventors, by Segment, 2012-15



Source: TEConomy/BIO Connecticut State Profile, 2016.

In addition, the relative *"impact" or "quality"* of a state's patent portfolio can be gauged using the forward citation of these patents in patent applications across the nation to identify where state innovations are viewed as fundamental building blocks for other inventions. Using a "forward citations" analysis, state strengths in terms of the quality of patents generated can be further isolated (see Figure 6).

Figure 6: Example of a Patent Innovation Cluster Analysis for North Carolina in Biosciences

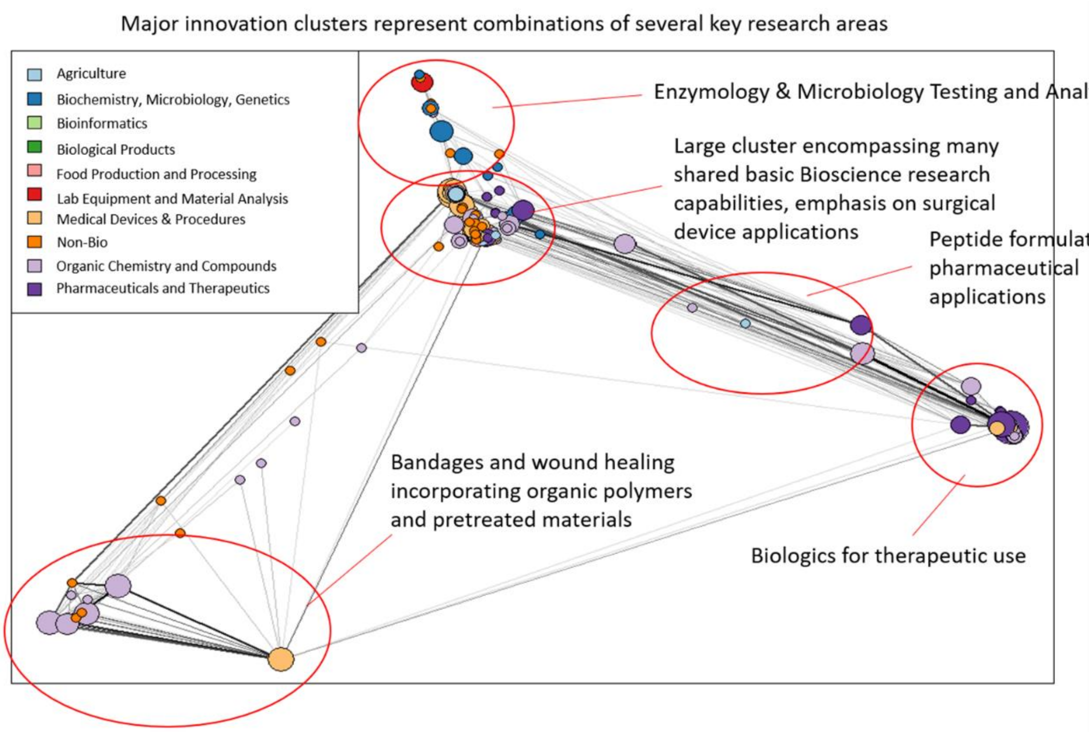


Figure notes:

- Bubbles represent individual classes
- Size of bubble represents number of forward citations from NC-invented patents
- Proximity of bubbles in graphic shows distinctiveness as either isolated or interrelated areas of innovation
- Thickness/darkness of lines represents forward citation relationships between patent classes

Source: Battelle Technology Partnership Practice.

An example of evaluating the technology transfer and commercialization activity of state universities is presented in Table 3. Unfortunately, this analysis of AUTM survey data does not allow for isolation of the life sciences or other disciplines, but it does speak to overall technology transfer performance. If the tech transfer offices of the universities within a state are willing to disclose further information, a bioscience specific analysis can be conducted. For example, in TEConomy's work in Arizona, we have further surveyed the tech transfer offices of the major research universities asking them to report specifically on the biosciences to develop a finer granularity of analysis specific to the biosciences.

Table 3: Example of University Technology Transfer Assessment from Washington State

Year	Total Research Expenditures	Invention Disclosures	Start-ups	Metrics per $10M in Research Expenditures					
				Invention Disclosures	Start-ups	New Patent Applications	U.S. Patents Issued	Licenses & Options Executed	License Income
Washington Universities (UW & WSU) & Fred Hutchinson Cancer Research Center									
2012	$1,559,264,003	568	16	3.64	0.10	1.90	0.51	1.66	$564,575
2013	$1,545,287,708	514	21	3.33	0.14	2.04	0.74	2.12	$716,804
2014	$1,696,502,787	565	25	3.33	0.15	1.59	0.55	2.06	$758,816
U.S. Universities									
2012	$56,319,944,381	21,033	647	3.73	0.11	2.25	0.81	0.97	$343,243
2013	$57,619,359,505	21,177	747	3.68	0.13	2.27	0.90	1.00	$361,058
2014	$56,093,085,688	21,395	840	3.81	0.15	2.21	1.04	1.09	$394,138

Source: TEConomy Partners, LLC analysis of Association of University Technology Managers (AUTM) survey.

Ecosystem Component: Entrepreneurial and Business Climate

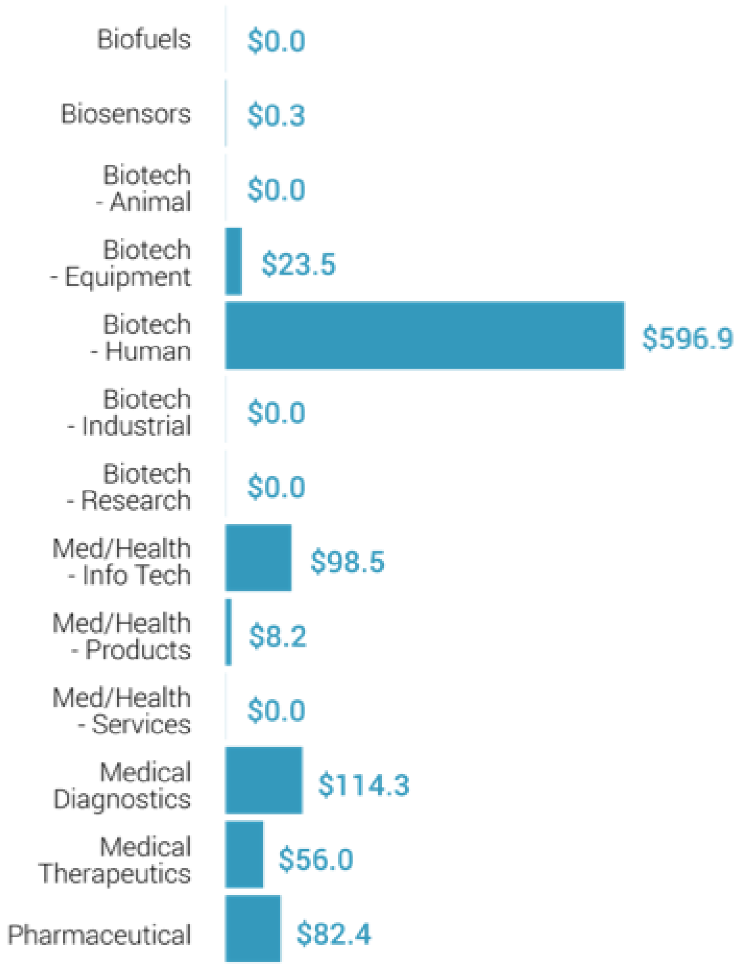
Newly formed bioscience firms rely heavily on seed- and early-stage funding and private risk capital to advance and translate scientific discovery, to develop proof-of-concept and prototypes, and to enter clinical trials, all before a product is commercialized and available in the market. It is important for a state to evaluate and track performance in innovation funding to its bioscience companies, from both private and public sources. Often gaps in access to capital are illuminated either at key stages of company development or to specific industry subsectors, highlighting areas for potential interventions or increased attention. In the case of Connecticut, for example, the investment portfolio of state-funded entities such as Connecticut Innovations can be evaluated via venture capital (VC) databases detailed in Table 4.

Table 4: Key Evaluation Metrics for Bioscience Innovation Capital and the Overall Entrepreneurial and Business Climate

Ecosystem Component	Key Concepts/Definitions	Data Source
Venture Capital (VC) Investments	• TEConomy has developed detailed definition of Bioscience-related VC segments (see Figure 7) • Important to track both deal flow volume (companies and deals); dollars invested	Thomson Reuters Thomson ONE database; PitchBook. **Both require paid subscriptions*
Federal SBIR/STTR Awards	• To isolate bioscience-related fields focus on awards from Dept. of Health and Human Services o Other Departments for searching for bioscience-related awards include Dept. of Agriculture; National Science Foundation; Dept. of Defense Important to track both award numbers and funding levels by award Phase.	SBIR database at sbir.gov
Ancillary related assessments: **Entrepreneurial Ecosystem** **Business Climate**	Sampling of broad measures for consideration: • Presence of high-growth companies (Inc. 5000) • Entrepreneurial activity (Kauffman Foundation's Startup Activity Index) • New Firm Start-up rate (Census) • Tax Climate (State Business Tax Climate Index) • R&D Facility Tax Burden (Tax Foundation) Business Climate Ratings (Forbes, CNBC, others)	Inc. 5000 The Kauffman Index of Startup Activity Tax Foundation R&D Facility Tax Burden: *"Location Matters: The State Tax Costs of Doing Business."* Tax Foundation, 2015. Forbes: Forbes Best States for Business CNBC: America's Top States for Business

A high-level depiction of Connecticut's own bioscience-related VC funding by industry segment is presented in Figure 7 from TEConomy's latest report with BIO.

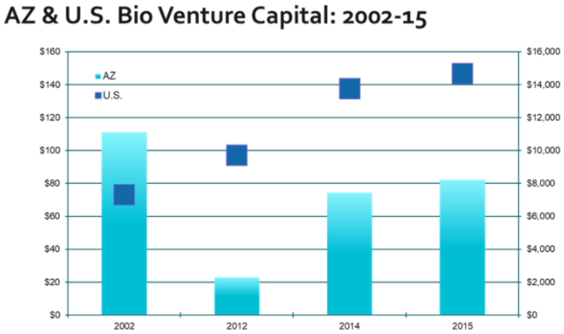
Figure 7: Connecticut Bioscience-related Venture Capital Investments by Segment ($ in millions), 2012-15

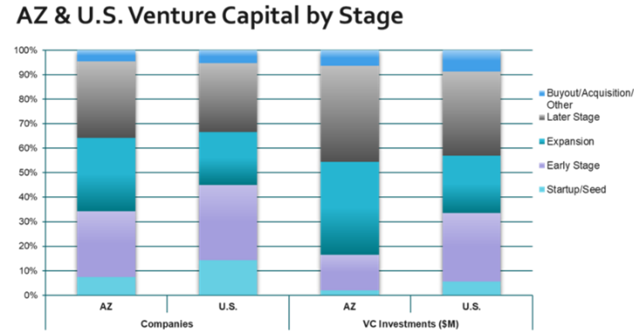


Source: TEConomy/BIO Connecticut State Profile, 2016.

The Flinn Foundation in Arizona has tracked annual VC investments in its bioscience companies since 2002, using a varied set of views to assess strengths as well as gaps (Figure 8).

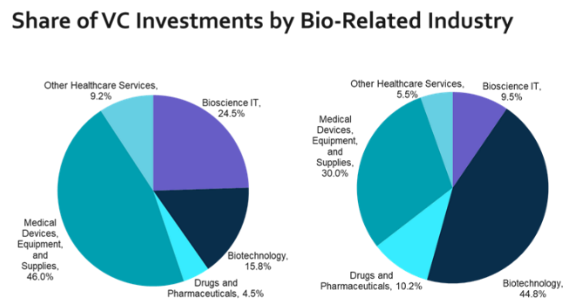
Figure 8: Examples of How Arizona Tracks Bioscience VC Investments





AZ & U.S. Bio Share of Venture Capital, 2002-15*

Metric	ARIZONA				U.S.		
	Bio VC	Total VC	Bio Share of Total AZ VC	AZ Bio Share of U.S. Bio VC	Bio VC	Total VC	Bio Share of Total U.S. VC
Number of Deals	126	479	26%	0.71%	17,833	67,147	27%
Number of Individual Companies Invested in	40	168	24%	0.78%	5,104	23,613	22%
Investment (in $ Millions)	$716	$3,687	19%	0.50%	$142,964	$567,345	25%



Source: Thomson Reuters Thomson One Database with TEConomy Partners, LLC Calculations.

Ecosystem Component: Bioscience Industry Base and Major Subsectors

The components along the innovation ecosystem development chain ultimately support a bioscience industry base that then feeds back into the aforementioned activities. States and regions that are targeting bioscience industry cluster development through strategic investment often look to the bottom line performance in terms of growing high-quality jobs. The Principals of TEConomy have tracked state by state industry employment, establishment, and wage performance with BIO since 2004. In addition, individual TEConomy clients regularly track their industry positioning and performance across key measures detailed in Table 5.

In our more than 12-year partnership with BIO, we have worked closely to develop a definition of the bioscience industry that has been accepted and adopted by numerous states and regions as well as State Bioscience Associations affiliated with BIO (see text box for description).

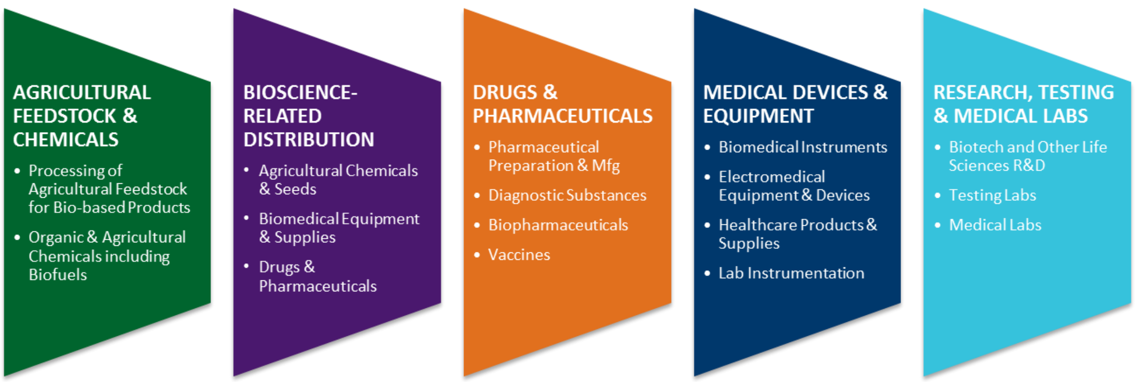
Table 5: Key Evaluation Metrics for Bioscience Industry Positioning and Performance

Ecosystem Component	Key Concepts/Definitions	Data Source
Bioscience Industry Employment, Establishments, and Wages	Key employment measures, by subsector, include: • Size – numbers of industry jobs. • Relative Concentration – industry location quotients represent the bioscience industry share of total state employment relative to that same share nationally, e.g. a LQ of 1.0 means state has same concentration seen nationally; an LQ≥1.2 said to be "*Specialized*" concentration of 20% or more. • Trends – both long- and near-term trends important to assess performance and evaluate key state investments. • State rankings or quintiles – used to assess relative performance, positioning.	U.S. Bureau of Labor Statistics (BLS), Quarterly Census of Employment and Wages (QCEW) "Enhanced" version of BLS, QCEW data from IMPLAN to fill in estimates for data cells that are suppressed due to confidentiality. **IMPLAN data set requires purchase.*
Bioscience Workforce	• In addition to broad industry assessment, expertise in innovation-driving, life science-specific occupations can be measured in a similar manner based on employment size, concentration (LQ), and trends.	U.S. Bureau of Labor Statistics, Occupational Employment Statistics (OES) program and State Labor Market Information offices
Bioscience Talent Generation	• Can measure talent pipeline and degree production in bioscience-related fields from state colleges and universities to gauge "supply" of talent and identify key academic programs or gaps.	U.S. Department of Education, National Center for Education Statistics (NCES), Integrated Postsecondary Education Data System (IPEDS) database

Defining the Bioscience Industry: Major Subsectors Reflect the Breadth of Life Science Opportunities

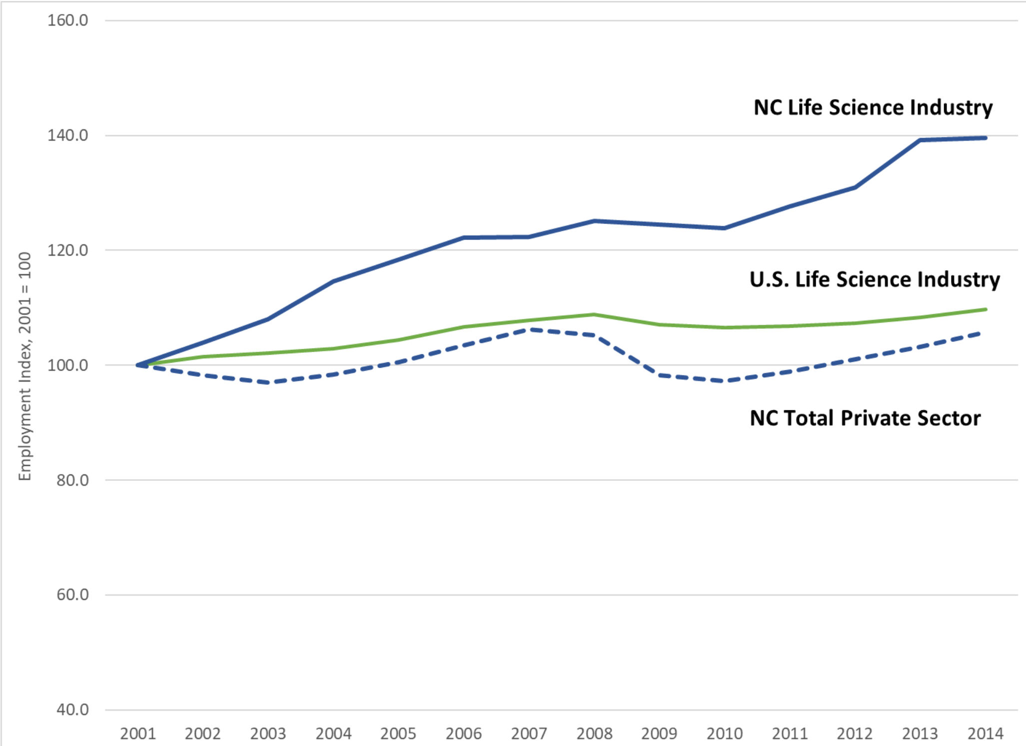
The biosciences, as an industry, span advanced manufacturing, research activities, and technology services but with a common thread or link in their application of life sciences knowledge and specifically how living organisms function. An industrial definition is challenging due to the diverse mix of technologies, products, R&D focus, and companies themselves. Federal industry definitions under the North American Industry Classification System (NAICS) do not identify one over-arching "life sciences" umbrella. Instead, 25 individual industry sectors at the most detailed classification level have been combined and organized by TEConomy across 5 major subsectors to track the industry's position and progress at the national, state, and local levels.

Major Bioscience Industry Subsectors



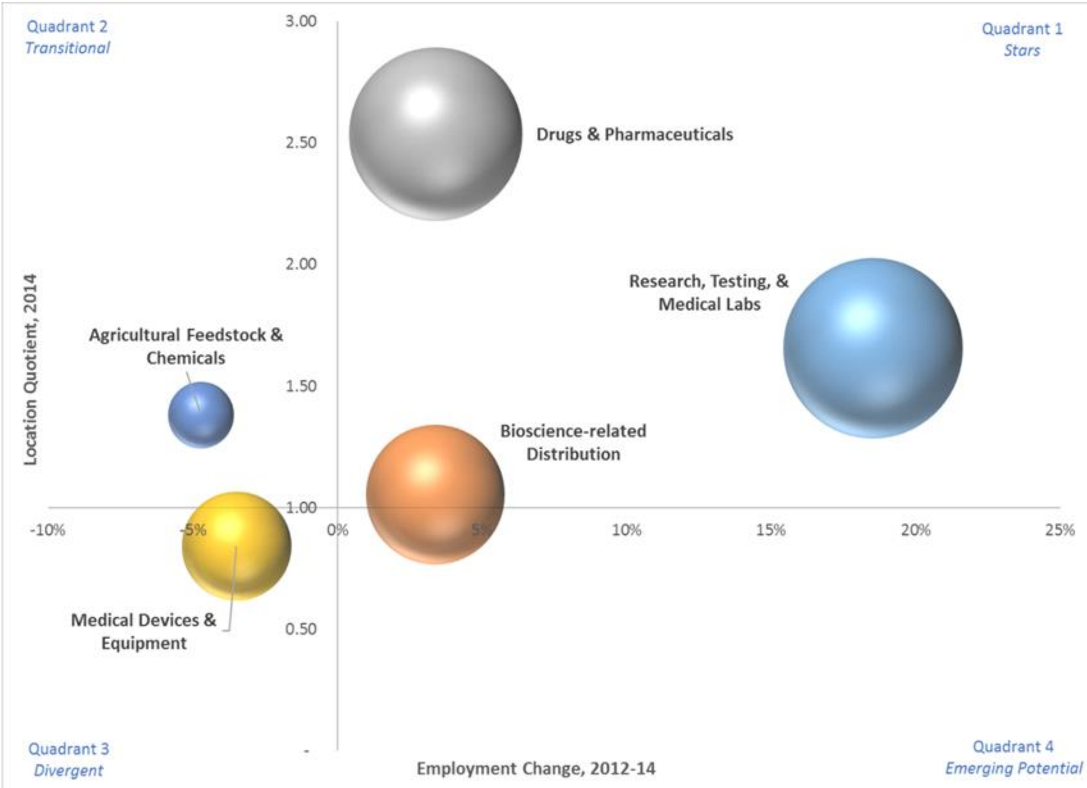
Figures 9 through 11 and Table 6 are examples of baseline assessments of North Carolina's bioscience industry, including some benchmarking against peer and competitor states. NCBiotech uses this analysis to inform the macro-level progress it is making to further develop and grow its bioscience industry based on its strategic programs and targeted investments.

Figure 9: Life Science Industry Employment Trends, North Carolina and U.S., 2001-14



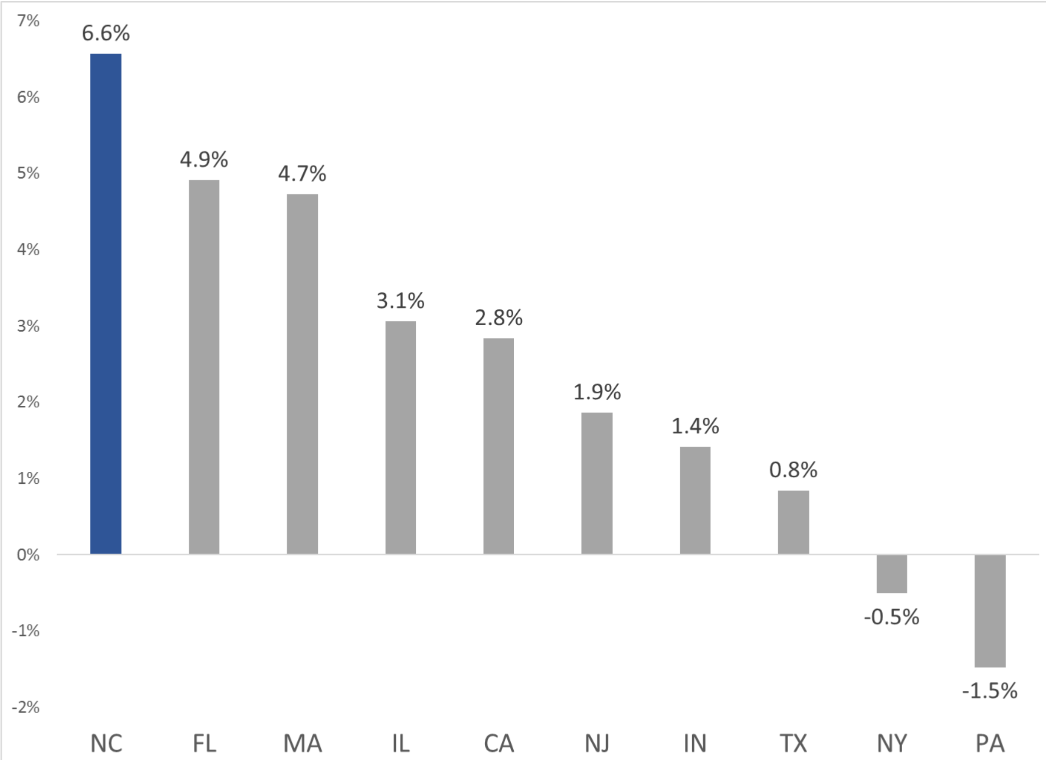
Source: TEConomy Partners, LLC analysis of BLS, QCEW data; enhanced file from IMPLAN.

Figure 10: NC Life Science Industry: Employment Size, Concentration, and Change, 2012-14



Source: TEConomy Partners, LLC analysis of BLS, QCEW data; enhanced file from IMPLAN.

Figure 11: Life Science Industry Employment Trends, North Carolina and Comparison States, 2012-14



Source: TEConomy Partners, LLC analysis of U.S. Bureau of Labor Statistics, QCEW data; enhanced file from IMPLAN.

Table 6: Average Annual Wages in the Life Science Industry and Major Subsectors, NC and U.S., 2014

Life Science Industry & Subsectors	North Carolina	U.S.
Drugs & Pharmaceuticals	$99,867	$117,524
Agricultural Feedstock & Chemicals	$88,908	$80,640
Total Life Sciences	**$87,158**	**$94,543**
Research, Testing, & Medical Labs	$86,279	$97,485
Bioscience-related Distribution	$85,089	$90,458
Medical Devices & Equipment	$60,063	$79,537
Total Private Sector	**$45,021**	**$51,148**

Source: TEConomy Partners, LLC analysis of U.S. Bureau of Labor Statistics, QCEW data; enhanced file from IMPLAN.

Ecosystem Component: A State's National Position/Rankings

The ultimate macro-level measurement for any state is the comparison of its performance and position against other states. In its strategic engagements with states, TEConomy often works to identify peer and competitor states for benchmarking comparisons. Similarly, in the biennial TEConomy/BIO report, while states are not explicitly ranked 1 to 50 in employment levels, they are grouped into tiers or quintiles, and in some cases, top states are presented for key measures. In presenting state-by-state comparisons, it is often most useful to "normalize" state comparisons, in other words, adjusting a measurement to account for the size of a state's population or economy (e.g. per capita measures, or per Gross State Product measures). Tables 7 through 10 provide examples of state rankings from the TEConomy/BIO 2016 report, including the summary table from the Connecticut state profile that includes quintile rankings.

Table 7: Summary of Connecticut's Performance in Bioscience-related Metrics

Metric	Connecticut	United States	Quintile
Bioscience Industry, 2014			
Bioscience Industry Employment	23,338	1,655,680	III
Bioscience Industry Location Quotient	1.15	n/a	II
Bioscience Industry Establishments	853	77,283	III
Academic Bioscience R&D Expenditures, FY 2014			
Bioscience R&D ($ thousands)	$802,460	$38,873,926	II
Bioscience Share of Total R&D	78%	61%	I
Bioscience R&D Per Capita	$223	$122	I
NIH Funding, FY 2015			
Funding ($ thousands)	$461,254	$22,869,746	II
Funding Per Capita	$128	$71	I
Bioscience Venture Capital Investments, 2012–15 ($ millions)	$980.0	$48,742.10	II
Bioscience and Related Patents, 2012–15	3,524	101,026	II

State ranking figures for bioscience performance metrics are calculated as quintiles, where:
top quintile — I II III IV V — bottom quintile

Source: TEConomy/BIO Connecticut State Profile, 2016.

Table 8: Leading States—Academic Bioscience R&D Expenditures & Growth, FY 2014

Academic Bioscience R&D Expenditure, 2014	
Leading States	**Total R&D Expenditure, $ Thousands**
California	$5,119,062
New York	$3,634,138
Texas	$3,011,942
Pennsylvania	$2,061,958
North Carolina	$2,049,435
Maryland	$1,668,335
Massachusetts	$1,515,537
Illinois	$1,396,626
Ohio	$1,318,183
Michigan	$1,214,255

Academic Bioscience R&D Growth, 2012-14	
Leading States	**Growth Rate, %**
Nevada	36.0%
Tennessee	17.0%
Utah	16.9%
Georgia	16.1%
Rhode Island	16.1%
Maine	14.0%
Connecticut	10.3%
Washington	9.5%
Delaware	9.3%
North Dakota	8.7%

Source: TEConomy/BIO report, 2016.

Table 9: Leading States—Per Capita and Concentration of Academic Bioscience R&D Expenditures, FY 2014

Academic Bioscience R&D Per Capita, 2014	
Leading States	$ Per Capita
District of Columbia	$488.55
Maryland	$279.20
Massachusetts	$224.35
Connecticut	$223.23
North Carolina	$206.17
New York	$184.02
Rhode Island	$162.53
Pennsylvania	$161.17
Iowa	$159.12
Nebraska	$158.13

Bioscience Share of Total Science and Engineering R&D, 2014	
Leading States	% Share
Missouri	83.3%
Arkansas	82.9%
Vermont	79.1%
Connecticut	77.7%
Kentucky	75.7%
North Carolina	74.8%
South Carolina	71.3%
Minnesota	70.1%
Alabama	70.0%
Wisconsin	69.8%

Source: TEConomy/BIO report, 2016.

Table 10: Leading States in Bioscience Venture Capital Investments, 2012-15

Total Bioscience Venture Capital Investment, 2012-15		Bioscience Venture Capital Distributions	
Leading States	Total in $ Millions	Leading States	$ Per 1M Population
California	$19,161	Massachusetts	$1,395
Massachusetts	$9,476	California	$489
Texas	$1,664	Connecticut	$273
Pennsylvania	$1,564	Maryland	$215
Washington	$1,523	Washington	$212
New York	$1,308	Rhode Island	$204
Maryland	$1,292	Colorado	$187
North Carolina	$1,262	Minnesota	$177
New Jersey	$1,214	New Hampshire	$142
Illinois	$1,139	D. of Columbia	$136

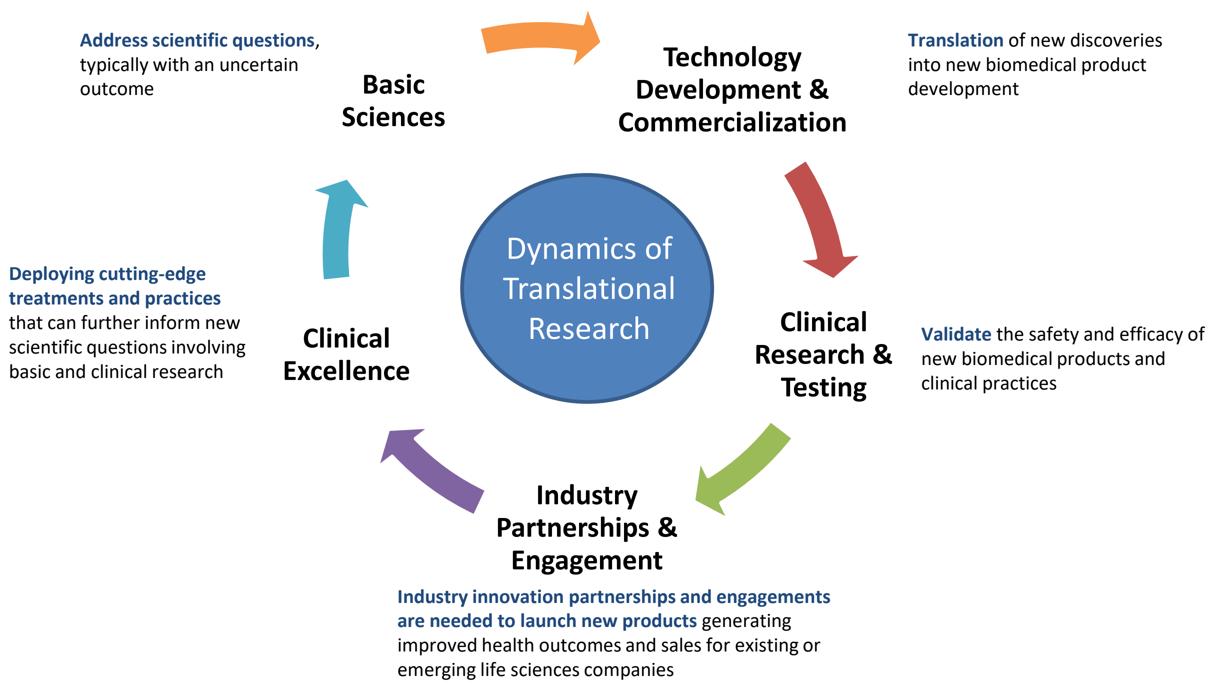
Source: TEConomy/BIO report, 2016.

Translational Research Perspective and Measuring Industry-University Connections

In addition to the innovation ecosystem perspective, the biosciences can be evaluated across a state or region using another important lens—the translational research perspective.

To move the bioscience industry forward, research must move from "bench to bedside", or what is termed the translational research cycle. As illustrated in Figure 12, this translational research paradigm takes into account the levels and inter-connections of basic research, technology development, clinical research and testing, industry partnerships and engagement, and clinical excellence that are needed to drive life sciences innovation and development. It is important to study a "translational research" perspective that maps the developments and connections from basic research through industry development.

Figure 12: A Translational Research Perspective on Bioscience Development



Source: TEConomy Partners, LLC.

In 2015, the principals of TEConomy worked with BIO to develop a framework for measuring industry-university connections for a report titled, *Advancing Translational Research for Biomedical Innovation*.[2] Recognizing the imperative for industry-academic partnerships to advance biomedical innovation, the report took stock of the progress made in advancing collaborations a decade after the NIH Roadmap and

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[2] Battelle Technology Partnership Practice, "*Advancing Translational Research for Biomedical Innovation: Measuring Industry-Academic Connections*," prepared for the Biotechnology Industry Organization, June 2015.

FDA Critical Path Report. The study gauged the level of engagement and contributions of industry and academia across four broad stages:

- Basic and applied research
- Technology development
- Clinical trials, and
- New product launch.

Across each of the four stages, the study presents key measures, at the national level, that can also be used to evaluate state-level industry-academic collaborations and partnerships (Table 11).

Table 11: Key Evaluation Metrics for Bioscience Translational Research Activity and Performance via Industry-Academic Collaborations

Ecosystem Component	Key Concepts/Definitions	Data Source
Industry-Sponsored University Biosciences Research	• Using the life sciences disciplines detailed previously, can track the dollars and share of University R&D expenditures that are funded by industry to assess levels/trends in partnerships, collaborations.	NSF Higher Education Research and Development Survey.
Industry-Academic Research Publications	• Identifying industry and university co-authors of scientific papers in the life sciences from state universities to assess levels/trends in partnerships/ collaborations.	Web of Science publications database; includes published research articles, proceedings papers, and reviews. **Requires paid subscription*
Industry-Assigned Biomedical Patents with Citations to Academic Journals	• Examining industry patents in biomedical technology classes to identify which cite academic research as foundational to the innovation.	Clarivate Analytics' Derwent Innovation patent analysis database **Requires paid subscription*
Industry-Funded Clinical Trials with a University Sponsor/Collaborator	• Federal clinical trials database identifies industry-funded trials where a university is also sponsoring or collaborating. • At a state level can identify state-based universities or academic medical centers acting as sponsors or collaborators.	NIH's National Library of Medicine maintains a database at ClinicalTrials.gov. Includes privately and publicly funded clinical studies conducted around the world.

If a state is investing in a matching grant program, for example, to incentivize life sciences industry-academic partnerships, these types of evaluation measures would be important to evaluate. Key measures and example figures from the report are provided below.

In the basic and applied research stage, extent of industry interactions can be evaluated by industry sponsorship for academic research, and co-authorship of research publications (Figure 13 and Table 12).

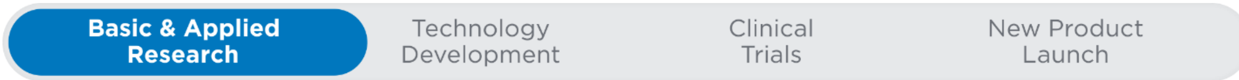
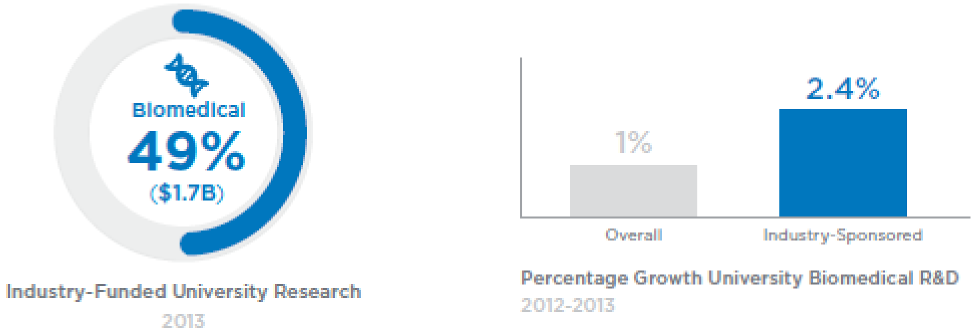


Figure 13: Industry-Funded University Research, 2012-13



Source: Battelle/BIO *Advancing Translational Research for Biomedical Innovation*, 2015.

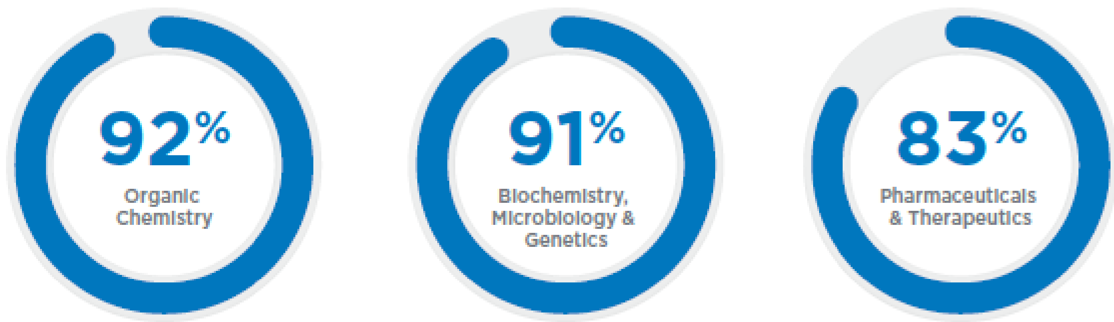
Table 12: Leading Biomedical Fields Represented in Industry-Academic Research Publications—Top 10 Growth Fields Over the Decade

Field	Growth
Neurology	118.9%
Surgery	112.7%
Health Care Sciences & Services	111.1%
Public Health & Health Care Science	103.8%
Rheumatology	100.8%
Metabolism & Nutrition	94.6%
Environmental Medicine & Public Health	85.2%
Hematology	71.0%
Gastroenterology & Hepatology	68.7%
Ophthalmology	65.2%

Source: Battelle/BIO *Advancing Translational Research for Biomedical Innovation*, 2015.

In the technology development stage, connections can be evaluated by examining industry patenting that cites academic research publications (Figure 14 and Table 13).

Figure 14: Percent of Industry-Assigned Biomedical Patents with Citations to Academic Journals by Primary Class Area, 2010-14



Source: Battelle/BIO *Advancing Translational Research for Biomedical Innovation*, 2015.

Table 13: Top Ten States with at Least 250 Industry Biomedical Patents Citing Academic Research, 2010–2014

State	Percent Share	State	Percent Growth
Maryland	74.5%	Oregon	216.3%
Washington	71.5%	Tennessee	206.3%
Colorado	71.1%	Minnesota	159.1%
Massachusetts	69.9%	Delaware	124.1%
North Carolina	67.7%	Florida	122.2%
California	67.4%	Illinois	106.4%
Connecticut	63.8%	Ohio	97.2%
Texas	62.4%	California	78.8%
New York	60.9%	Arizona	78.7%
Pennsylvania	60.8%	Colorado	78.5%

Source: Battelle/BIO Advancing Translational Research for Biomedical Innovation, 2015.

When moving to the clinical trials stage, industry led trials with a university sponsor or collaborator can be identified (Figure 15).

Figure 15: Share of U.S. Industry-Funded Clinical Trials with a University Sponsor/Collaborator

Source: Battelle/BIO *Advancing Translational Research for Biomedical Innovation*, 2015.

In the late stages of translational research, industry-academic connections can be evaluated with the launch of a new therapeutic, for example, where industry is citing academic research (Figure 16).

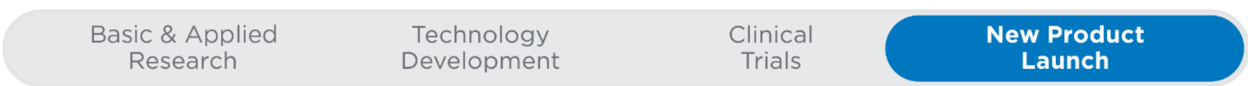
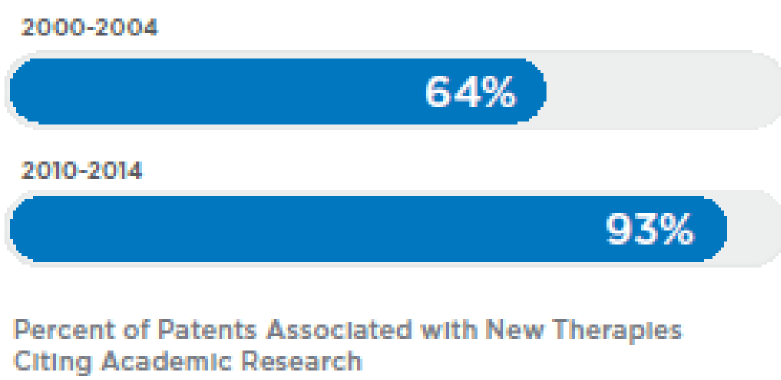


Figure 16: Share of Patents Associated with New Therapies Citing Academic Research



Source: Battelle/BIO *Advancing Translational Research for Biomedical Innovation*, 2015.

The perspectives offered in this section for both the interconnected innovation ecosystem and the translational research paradigm can provide a broader context for the evaluation or performance measures they encompass. As a state invests strategic resources to address key components or facets of their state ecosystem or to boost collaborations between industry and universities to strengthen translational research, the measures presented in this section are important to evaluating results and outcomes.

III. Evaluating State Bioscience Investments at a "Micro" Level

In addition to measuring the macro, state-level outcomes of the innovation ecosystem and/or the translational research paradigm, many states are investing in specific programs and/or institutions and as a result have a need to understand the returns or outcomes associated with these more "micro" level initiatives. TEConomy has assessed both life science-related and broader technology-focused organizations/programs at this more granular level. This section provides examples and guidance for these types of micro-evaluation approaches and metrics.

There are two specific ways to analyze direct investment impact at the micro level:

- Direct, proximate measures of success, and
- Input/Output Economic Impact Modeling.

The following narrative describes both analytic evaluation approaches and provides examples of each.

Direct, Proximate Measures of Success

Bioscience investments through technology-based economic development initiatives are geared towards catalyzing the commercialization process by optimizing investments at key stages of development throughout a technology's life cycle. However, in order to help determine if investments should continue to be made in particular areas, it is necessary to track proximate measures of success in order to improve the quality of decision making at an individual project or initiative-level basis by integrating into the analysis measures that predict the likelihood of a technology receiving additional financial investment.

The proximate, or near-term, measures of success will vary depending on where within the life cycle an investment is being made, and therefore it is important to ensure suitable metrics are being analyzed. Too often, the "jobs created" metric is used for all technology-based economic development investments, when the creation of jobs will not occur for many years. The problem with using job creation as the metric of success is that the programmatic leadership either loses funding when job numbers are not met quickly (which is not realistic) or programs that are mediocre are allowed to continue on for years under the promise of future jobs when in reality all of the proximate measures of success indicate the project will not be successful. Both outcomes are equally undesirable.

It is for these reasons that bioscience projects/initiatives should clearly define what their proximate measures of success will be and then work diligently to collect and analyze these measures to determine if the project outcomes are being met, and if not, to make adjustments in the investment portfolio based on the findings.

Below is a list of potential proximate measures of success at each stage in the bioscience innovation ecosystem. While the list is not exhaustive, and each individual project and/or initiative will need to define its own proximate measures, this list can serve as a starting point. It is important to note that all of these measures are outcome oriented – tangible measures of success that are the result of the technology moving through the commercialization life cycle. Measures include:

- Research & Development
  - As a result of state funding of a project and/or initiative, the level of:
    - Cost-share received
    - Follow-on investments received from:
      - Federal government
      - Industrial funding
      - Additional state funding
      - Other funding
- Commercialization & Deployment
  - Patent Activity
    - Number of patent applications submitted
    - Number of patents issued
  - Licensing Activity
    - Number of technologies licensed from the project/initiative within the state
    - Number of technologies licensed from the project/initiative outside the state
    - Licensing revenue received as a result of the project/initiative from within the state
    - Licensing revenue received as a result of the project/initiative from outside the state
- Entrepreneurial Growth
  - Number of companies created
  - Income generated from:
    - Sales revenue
    - Other income
  - Equity investment received from:
    - Angel investors
    - Private equity/holdings
    - Venture capital
    - Other
  - SBIR/STTR/Federal Research Grant Activity
    - Applications submitted (broken out by Phase I and II)
    - Number of awards received (broken out by Phase I and II)
    - Dollar value of awards received (broken out by Phase I and II)
  - Number of jobs created
- Business Development/Scalability
  - Number of Companies involved in project/initiative
    - Increase in product sales/sales revenue from new product development
    - Increase in R&D investment
    - Jobs Created
    - Total Jobs
    - Annual Aggregate Client Payroll
    - Average Salary per Job
    - Number of companies attracted to state as a result of initiative

Best Practices for Program Evaluation: Importance of High-Quality, Consistent Data Collection

The Principals of TEConomy have worked with numerous state organizations and programs that are making targeted, taxpayer-funded investments and want to evaluate and report on the outcomes of these programs. To do so in a sound and defensible manner, it is absolutely crucial for the organization to collect high-quality data specific to the investments whether that be individual companies receiving grants or loans, or research institutions awarded funding to promote strategic research or commercialization.

Organizations like NCBiotech stand out in this aspect and offer an example of a "best practice". The Center employs research librarians to maintain company-level databases of both their program participants as well as the entire life sciences industry across the state that include addresses, industry subsector, and employment levels over time. This regular tracking and updating of information allows for the regular assessment of the industry's economic impacts both statewide and at regional levels, which are key to the economic development context in which they operate. In addition, it allows for the assessment of the Center's interventions from specific programs to track employment growth, company expansions and contractions, and company recruitment into the state.

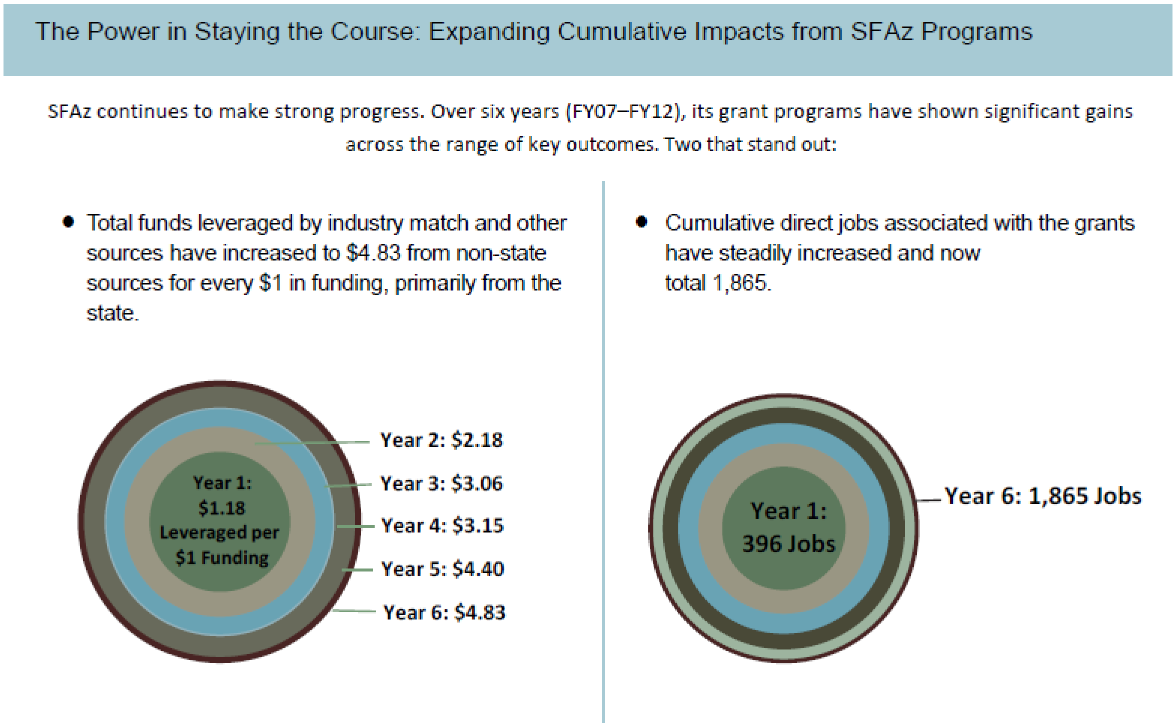
TEConomy has engaged with clients that do not have these high-quality tracking and database systems in place and this situation can severely limit the ability to report on an organization's impacts.

Evaluation Example: Science Foundation Arizona

Science Foundation Arizona's (SFAz) annual evaluation report includes examples of proximate success measurement.[3] SFAz is a public-private partnership focused on strengthening and diversifying Arizona's technology-driven economy. The organization, through a diverse set of grant programs and other activities, works to connect Arizona researchers and businesses to encourage commercialization of research and to advance STEM education. One of its primary focus areas is the biosciences, but its activities span a range of other technology areas as well. The following are examples from the SFAz evaluation, which was based on annual surveys of its grant recipients. The examples highlight the progress in outcomes and returns associated with their programs and initiatives (Figure 17).

[3] Battelle Technology Partnership Practice, "Measuring Up: 2013 Annual Report Card on How Arizona's Technology Sector is Performing and the Contributions of Science Foundation Arizona," June 2013. For more on SFAz programs and their impacts, and to access the 2013 Battelle report, visit http://www.sfaz.org/impact/.

Figure 17: Cumulative Impacts of Science Foundation Arizona's Programs, FY2007-2012



Source: Battelle Technology Partnership Practice, "Measuring Up: 2013 Annual Report Card on How Arizona's Technology Sector is Performing and the Contributions of Science Foundation Arizona."

SFAz's commercialization performance stands out compared to typical statewide university activities—pointing to the success of its focus on moving scientific advancements to the marketplace:

- One patent applied for or issued for every $1.6 million in total university research funding generated over the past six years, well ahead of the six-year Arizona university-wide average of one patent per $4.2 million in funding.
- One new company start-up for every $14.2 million in total university research funding generated over the past six years, well ahead of the six-year Arizona university-wide average of one start-up per $86.7 million.

SFAz Programs Continue to Expand Direct Cumulative Impacts:

SFAz grant activities continue to make progress and generate significant impacts. Over the past year, SFAz grant programs have:

- Increased total funds leveraged by industry match or other sources by $26.3M; in turn increased its leverage per dollar awarded by $0.43 to $4.83 from non-state sources for every $1 in funding, primarily from the state
- Increased direct jobs associated with the grants by 89 to 1,865
- Increased patents filed or issued by 28 to 207
- Increased companies formed by 2 to 24
- Increased technology licenses by 7 to 23
- Increased scientific publications by 345 to 1,947
- Broad student involvement in STEM education programs (both direct and indirect) with 70,742 impacted this year and 6-year totals of nearly 385,000, and
- Extensive teacher involvement in STEM education programs (both direct and indirect) with 2,583 this year and a 6-year total of 10,656.

Source: Battelle Technology Partnership Practice, "Measuring Up: 2013 Annual Report Card on How Arizona's Technology Sector is Performing and the Contributions of Science Foundation Arizona."

Input/Output Economic Impact Modeling

A state's investments in significant bioscience projects/centers/laboratories have direct operational economic impact. In addition, many of these expenditures are then recirculated within each impacted economy as recipients of the first round of income re-spend a portion of this income with other businesses and individuals within the economy. This re-spending is termed the "multiplier effect" (incorporating both indirect and induced economic impacts).

The standard analytical technique for the quantification of expenditure impacts is input/output (I/O) analysis. I/O analysis uses a matrix representation of an economy that quantifies the impact of spending by one sector of the economy (e.g., the biosciences) on all other sectors, consumers, and government. The analysis uses the IMPLAN Group's software and data systems for application of I/O analysis. The I/O methodology calculates the expenditure impacts of a specific bioscience investment across multiple measures, including the following:

- **Economic Output**, also known as business volume, is the total value of goods and services produced in an economy and represents the typical measure expressed as "economic impact" in a standard economic impact study.
- **Income** is the total amount of income received by labor in the economy because of the presence and operations of the investment—both directly via the investment's payrolls and induced through the multiplier effect within the economy.
- **Employment** includes both direct employment as a result of the investment, but also the jobs within the economy supported by the investment-related business volume (indirect employment).

The I/O model represents the interrelationships among economic sectors and subsectors. I/O data show the flow of commodities to industries from producers and institutional consumers for any given state. The data also show consumption activities by workers, owners of capital, and imports from outside the region. These trade flows built into the model permit estimating the impacts of one sector on other sectors. These impacts consist of three types:

- **Direct effects** (the specific impact of the firm and/or sector(s) in question),
- **Indirect effects** (the impact on suppliers to the focus industry or firm), and
- **Induced effects** (the additional economic impact of the spending of these suppliers and employees in the overall economy).

The summation of these three effects are considered the total impacts.

Each IMPLAN model uses detailed region- and sector-specific information to estimate outcomes and gauge potential impacts. The model incorporates details of 536 individual industry and economic sectors that cover the entire state economy. With these sector possibilities, the analysis can more precisely model the impact of a specific bioscience investment by aggregating the operational characteristics and production functions of the various aspects of the investment's operations.

Evaluation Example: The North Carolina Biotechnology Center

In TEConomy's biennial assessments with NCBiotech, our team has worked with the Center to measure the economic impacts of specific programs targeting industry development. In addition to measuring the economic impacts of the entire life sciences industry and university research in North Carolina, we have utilized economic impact modelling to measure, for example:

- The impacts of NCBiotech's targeted, early-stage loans to life science businesses. The Center's portfolio represents a long-term investment in companies participating since 1989 and impacts assessed include companies still in operation today. Of the 188 companies that have received loans, 102 are currently active in some form and these companies employ 2,914 workers. TEConomy estimated the economic impacts of these 102 companies. As presented in Table 14, these 102 companies had total employment of 2,914 and estimated revenues of $2.8 billion and generate:
    - $4.3 billion in economic activity in the state
    - Create or support 12,666 jobs earning $887 million in labor income, and
    - Generate an estimated $115.9 million in state and local tax revenues.

  The ability to report on the impact of these companies, including what they generate in fiscal returns to the state, has been especially useful to NCBiotech's ability to present its impact and make the case for continued state funding for its efforts.

Table 14: The Economic Contribution to the North Carolina Economy of the 102 Currently Active Companies that Received NCBiotech Business Loans

	Output (Mil. $s)	Labor Income (Mil. $s)	Employment	State/Local Tax Revenue (Mil. $s)
Total Life Science Industry Impact				
Direct Effect	$55,324	$6,654.8	62,937	$700.9
Indirect Impacts	$19,278	$7,295.7	108,590	$891.7
Induced Impacts	$11,761	$3,758.4	88,437	$582.0
Total Impact	$86,364	$17,708.9	259,963	$2,174.6
Impact of the 102 Currently Active Companies that Received Business Development Loans				
Direct Effect	$2,760	$331.6	2,914	$34.2
Indirect Impacts	$957	$366.7	5,307	$51.9
Induced Impacts	$591	$188.9	4,444	$29.8
Total Impact	$4,308	$887.2	12,666	$115.9
Share of Total Industry Impact				
Direct Effect	5.0%	5.0%	4.6%	4.9%
Indirect Impacts	5.0%	5.0%	4.9%	5.8%
Induced Impacts	5.0%	5.0%	5.0%	5.1%
Total Impact	5.0%	5.0%	4.9%	5.3%

Source: TEConomy Partners, LLC analysis of NCBiotech data using IMPLAN Input/Output model for North Carolina.

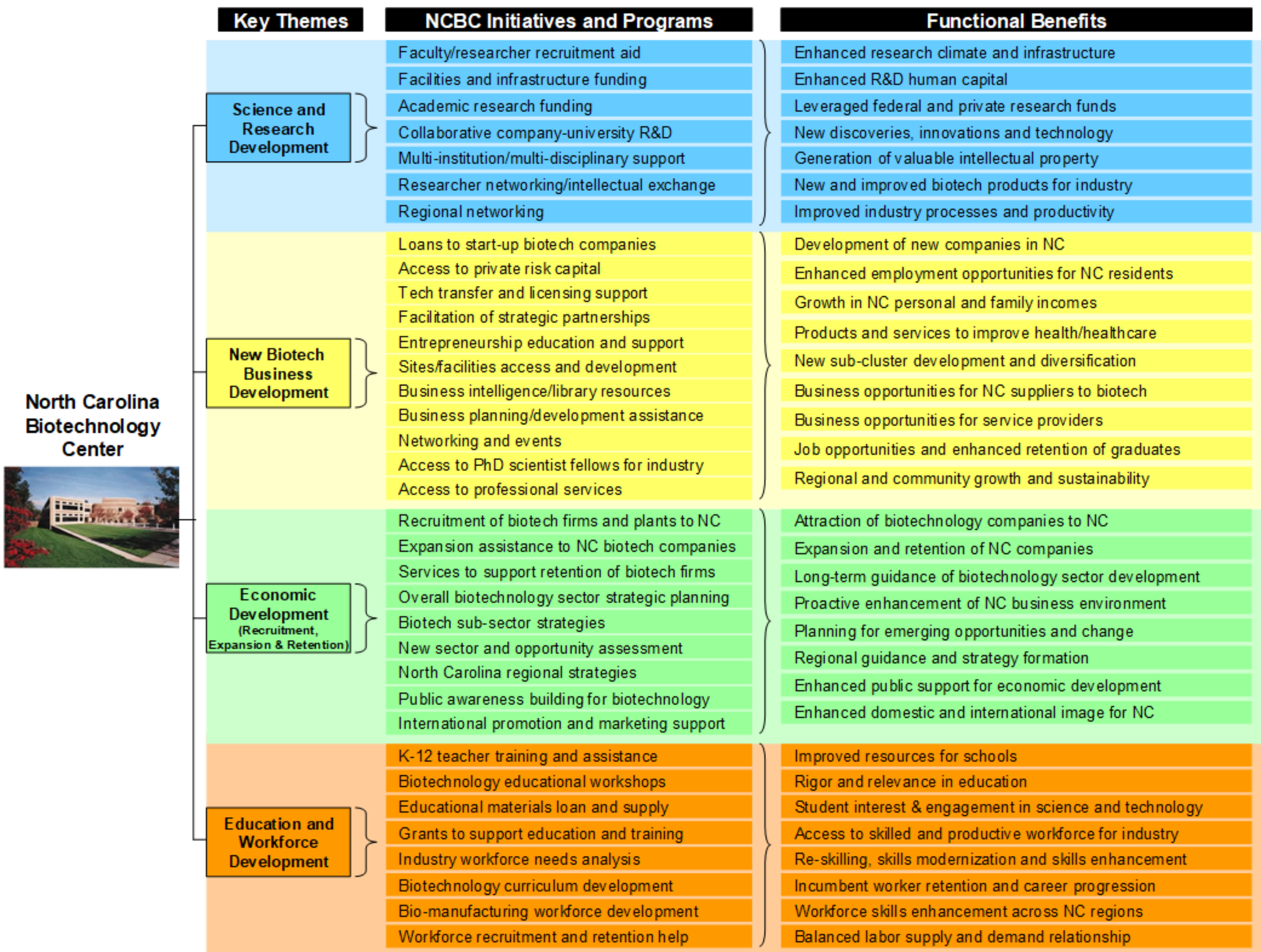
- The impacts of NCBiotech's active recruiting efforts, as well as its support for existing state companies for expansion of their operations within the state. In the 2016 report, TEConomy assessed the economic impacts of the recent recruitments of companies into North Carolina, which numbered 16 during the 2015-2016 time period.
  - Based on data provided by the Center, these 16 companies have the potential to create a total of 2,158 jobs once they reach projected employment levels. TEConomy's analysis estimated that once the companies involved in these 16 projects attain their full projected level of employment, they will generate $2.8 billion in economic activity and support 8,526 jobs earning $600 million in labor income and generate $73 million in combined state and local government revenues.

In addition to quantitative analysis of a program's economic impacts, it is extremely important to highlight the "functional", or forward-linking, impacts of an organization's mission. This helps to complement the activities that can be quantitatively estimated and communicates a powerful storyline or narrative of benefits to a state.

In its 2010 report, the Biotechnology Center's functional benefits were organized into the four primary activities of the Center (Figure 18):

> *"Placing the primary activities of the Biotechnology Center into the four simplified categories … helps to explain the operations of the Center but oversimplifies the complex suite of programs, services and initiatives deployed by the Center under these four categories. The figure provides a more detailed view of the specific functional activities that the Center deploys in meeting its mission and goals:"*

Figure 18: North Carolina Biotechnology Center Initiatives and Programs and their Functional Benefits for North Carolina



Source: Battelle Technology Partnership Practice report for the North Carolina Biotechnology Center, 2010.

Evaluation Example: The University of Arkansas for Medical Sciences (UAMS)

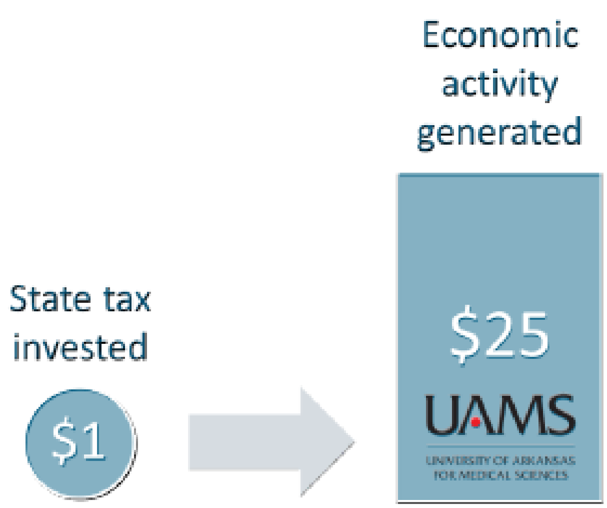
The State of Arkansas invests significant funding into UAMS ($107 million in 2015), the state's only comprehensive academic medical center. UAMS plays an important role in not only administering health services but also educating the state's physician workforce, producing nearly half of the state's practicing physicians. UAMS engaged TEConomy in 2016 to help it better understand and communicate the economic impacts it contributes to the state economy.[4]

Using data and information provided by UAMS regarding its employment levels and composition, salaries, budgets, and other information, TEConomy was able to utilize economic impact modelling via IMPLAN's I/O models for Arkansas to estimate impacts and an ROI to the state based on its investments in the system.

Key findings from the study include:

- UAMS is one of the state's greatest economic engines generating $2.65 billion in economic activity statewide. For every dollar of taxpayer money that UAMS receives, $24.53 of economic activity is supported across the state economy (Figure 19).

Figure 19: University of Arkansas for Medical Sciences Return on Investment, 2015



Source: TEConomy Partners, LLC analysis.

- The economic impact generated by UAMS and its regional program stems from both its direct employment and expenditures, as well as the secondary and tertiary economic activity generated when UAMS procures goods and services from other Arkansan companies and through personal spending by UAMS employees. These employment and expenditure impacts reverberate positively throughout the statewide economy through, what is generally termed, the "multiplier effect."

[4] TEConomy Partners, LLC, "*The Economic Impact of The University of Arkansas for Medical Sciences and Its Affiliate Systems*", December 2016.

- When these secondary and tertiary impacts are considered, UAMS and its regional program support 20,107 jobs across the state and generate $336 million in Federal, state, and local tax revenue, up from 18,487 jobs and $272 million in Federal, state, and local taxes in 2010 (Table 15).

Table 15: Total Statewide Economic Impact of UAMS and its Regional Program, 2010 and 2015

	Output ($Bn)	Employment	Wages ($Bn)	Taxes ($M)
2010	$2.112	18,487	$1.068	$272
2015	$2.649	20,107	$1.307	$336

Source: TEConomy Partners, LLC analysis and calculation using Arkansas county-level IMPLAN impact models.

The study goes on to detail the impact of UAMS' educational programs, its clinical care services, research activities, its innovation and commercialization outcomes including spin-outs, and its regional impacts across Arkansas. The impacts generated by the institution help to make a case for increased funding from the state, particularly in the context of declining state funding to UAMS in recent years.

IV. Conclusion

This report has presented examples of measures and approaches that are used to evaluate state bioscience investments at both the macro (state) and micro (organization/programmatic) levels. A combined macro/micro approach to assessing the impacts and returns on state investments is often the most complete and appropriate, though with the biosciences in particular, the expected timeline for returns or the "payoff" from investments can often take many years.

The most relevant measures to utilize at a macro-level for any given investment will vary depending upon the type of initiative or program and its intended focus. For instance, a program designed to advance industry-university partnerships in the biosciences would be expected to impact the ecosystem differently than one with a goal of expanding access to venture capital. That said, as the State of Connecticut moves forward in analyzing at a macro-level the impact of its portfolio of investments to foster the bioscience industry across the state, it is recommended that the analysis generally focus on the following key measures:

- Level of bioscience-related R&D activity, including:
  - Industrial R&D
  - Academic R&D
  - Industrial support for academic R&D
- Level of ongoing translational research, including tracking industry-university collaborations:
  - Industry-sponsored university bioscience research
  - Industry-academic research publications
  - Industry-assigned biomedical patents with citations to academic journals
  - Industry-funded clinical trials with a university sponsor/collaborator
- Level of technology commercialization, including:
  - Bioscience-related patenting by industry
  - Bioscience-related university technology transfer activity
- Robustness of Connecticut's entrepreneurial and business climate, including:
  - Amount of bioscience-related risk capital investments
  - Number of bioscience-related entrepreneurial and high-growth enterprises
  - Rankings within entrepreneurial and tax climate indices
- Size, growth, and concentration of Connecticut's bioscience industrial base, including:
  - Bioscience industrial establishments
  - Bioscience employment and wage rates
  - Accessibility of bioscience workforce
  - Generation of bioscience talent
- National reputation and overall state positioning, including:
  - Biennial rankings/tiers within the TEConomy/BIO State profiles

In addition, because of specific investments that the State of Connecticut has made in programmatic activities, such as CBIF, BioScience Facilities Fund, Bioscience Connecticut, JAX Genomic Medicine, RMRF, and CI, the state may also wish to examine at a programmatic level the returns or outcomes associated with these more "micro" level initiatives. There are two specific ways to analyze direct investment impact at the micro level:

- Direct, proximate measures of success, such as:
    - Follow-on investments/funding leveraged
    - Direct jobs created
    - Number of companies created/entrepreneurial growth
    - Business development/scalability
- Input/Output Economic Impact Modeling to calculate the broader economic impacts of expenditures that result from direct programmatic investments through measures such as:
    - Economic output
    - Income
    - Employment
    - State and local tax revenues generated.
- Functional impacts, or forward-linking impacts, of an organization's activities as a direct result of its mission/outreach emphasis.

This report has included references to and examples of these types of assessments, all of which are publicly-available studies for the State of Connecticut to learn from as it moves forward with its assessment activities. **It is important to note,** the macro level data is available from public or publicly-accessible subscription data sources; however, the **micro level data can only be obtained with the cooperation/participation of the programmatic initiatives, and even then, only if the information/metrics have been tracked in a high-quality manner over time.** In particular, for the micro-level, direct, proximate measures of success, this information is not publicly available and can only be analyzed if the programmatic entity has tracked the information and is willing to provide the data.

The State of Connecticut has made significant investments over time to grow its bioscience industrial base, and as a result, it is important to understand how these taxpayer-funded initiatives are impacting the state's economy and its citizens by analyzing, evaluating, and communicating the economic and societal return on the state's investment. It is therefore recommended that an independent, third-party entity with the requisite expertise be engaged to gather the relevant data from the various parties that will need to participate to ensure a thorough review, undertake the analysis as outlined in this bioscience evaluation framework, and communicate its findings in a clear, concise, and meaningful manner to key stakeholders throughout Connecticut.