Research-Asset Assessment Study for Commonwealth of Virginia:

Phase I – Initial Gap Analysis on the Advancement and Translation of Virginia's Research and Development Assets

To: **Virginia Research Investment Committee and State Council of Higher Education for Virginia**

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TECONOMY PARTNERS LLC

Innovating Tommorow's Economic Landscape

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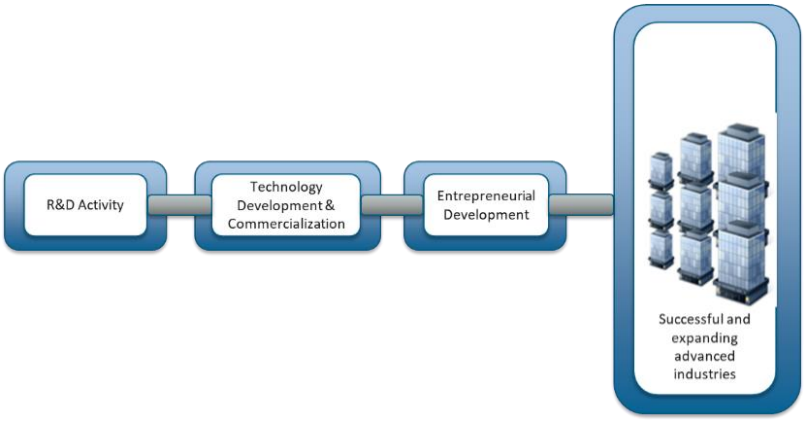
A. Introduction

The advancement and translation of Virginia's research and development assets to drive commercialization and economic activity requires a high functioning innovation ecosystem. This innovation ecosystem must now measure up to the challenges posed by a global, knowledge based economy. A new economic era has been taking hold in recent decades marked by increasing globalization, the fast pace of technological change, and the growing strength of developing nations in generating highly educated and skilled talent to compete for economic growth.

As the National Research Council in its 2013 report on *Best Practices in State and Regional Innovation Initiatives: Competing in the 21st Century* explains: "States [and regions] confront stark economic challenges in the global era ... efforts at industrial revival using traditional policy tools, including industrial recruitment and financial incentives to industry are now being complemented by more technology-based indigenous growth strategies."[1] The National Research Council continues by noting that: "In the years since [late 1970s] ... state and local industrial development efforts have continued unabated while undergoing a qualitative evolution that increasingly emphasizes knowledge-based development ... In recent decades, however, innovation-related initiatives have moved to the center of state and local development efforts."[2]

While economic development is not easy to achieve in general, innovation-led economic development presents an even greater challenge. Innovation capacity generates economic growth through an interconnected value chain of public and private economic development resources and services to translate research and development activities through commercialization to foster new enterprise development, growing existing industry, and attracting new businesses. If any link in the chain in missing as depicted in Figure 1, then a region will not realize its full potential in advanced industry development.

Figure 1: Linkages in an Innovation Ecosystem Leading to Economic Development



[1] Charles W. Wessner, Editor. *Best Practice in State and Regional Innovation Initiatives*. Committee on Competing in the 21st Century; Board on Science, Technology, and Economic Policy; National Research Council, 2013, page 11.
[2] IBID, page 28.

The performance of Virginia's innovation ecosystem depends upon the state's capacities and connections in its innovation value chain including its research and development activities, technology development and commercialization activities and entrepreneurial development activities. The best way to think of a high-functioning innovation ecosystem is through the paradigm of translational research that bridges the research activities of universities, federal labs and industry to generate new discoveries that result in new intellectual property, which is then used as the basis of new technology development for commercialization, leading to the launch of new products by existing businesses and new business start-ups. Ultimately, the value of innovation at the scale of the state's economy is demonstrated by being able to generate growing advanced industries that leverage the innovations and expertise generated through those innovations.

But the process of innovation is not simply a pipeline, but a more complex, bi-directional feedback loop in which market needs and requirements inform and shape the process by which translational research moves forwards and succeeds in generating economic value. The complexity of innovation raises the need to consider how well functioning Virginia is both within and across the different stages of a state's innovation ecosystem. This report does that in several ways.

First, it takes a broad view to consider Virginia's capacities at each stage of the innovation ecosystem with objective measures of performance. This involves drawing upon a multitude of databases to compare Virginia to the nation across key measures of innovation capacity found at each stage of the innovation ecosystem. These national comparisons examine the level of Virginia's activity relative to the size of the state's economy compared to the nation and growth trends over the 2010 to most recent year of data availability, typically 2015.

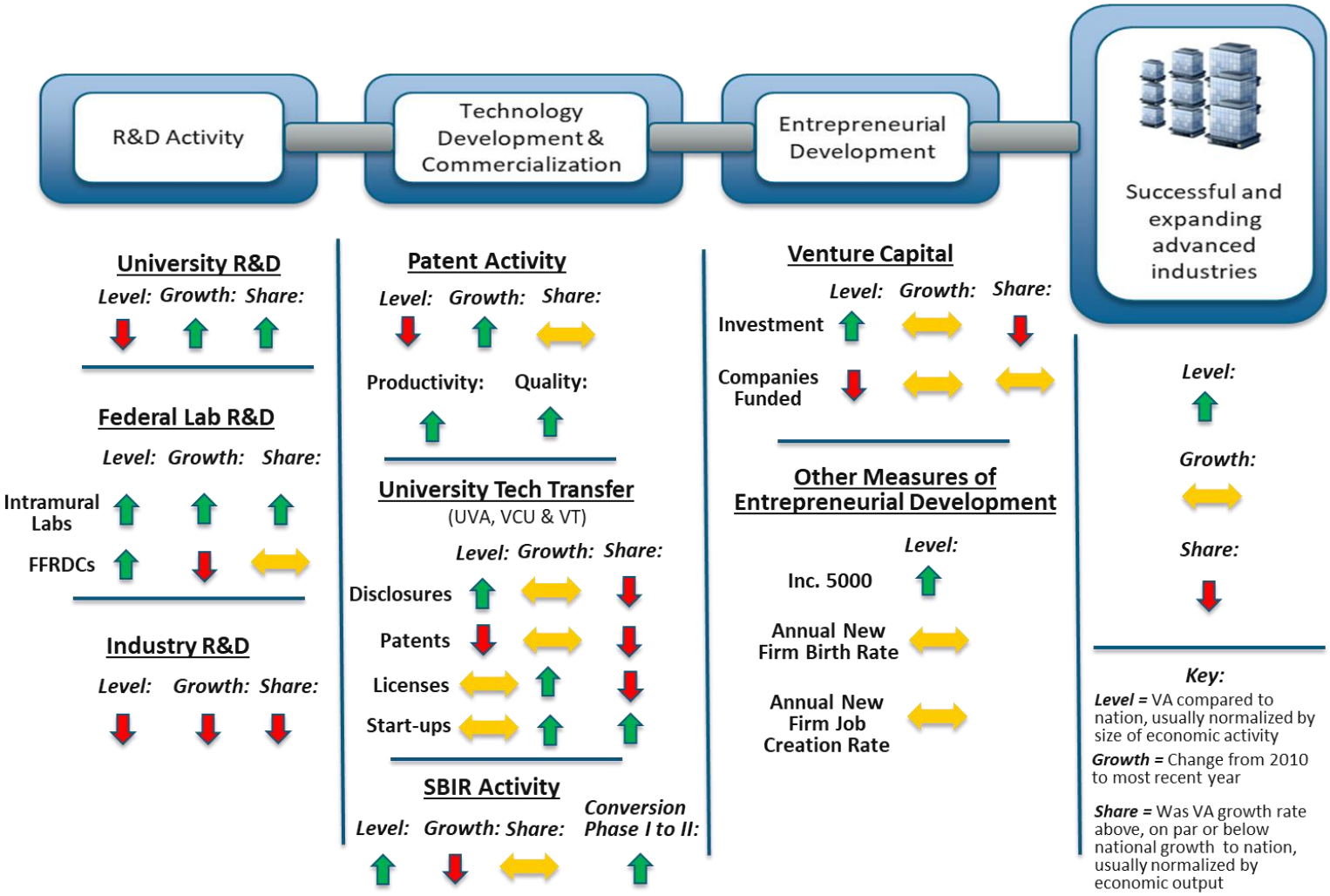
It is also important to get below the surface of the innovation capacity metrics and consider the dynamics taking place in Virginia's innovation ecosystem. One important dynamic is the changing nature of sources of funding for university, federal lab and industry research activities. Another is the connections taking place across industry, universities and federal labs in their research and technology commercialization activities, as well as the alignment of university and federal lab research competencies with industry research activities.

B. Summary Findings

The broad view of Virginia's innovation ecosystem capacities and dynamics primarily focused on comparing Virginia to the nation with objective measures of the level and trends in performance found at each stage of the innovation ecosystem and within specific funding streams and areas of industry connections with university and federal labs.

The results of this initial analysis of Virginia's innovation ecosystem capacity and dynamics suggests that despite a solid base of advanced industry in the state and the strong presence of federal intramural labs and FFRDCs, Virginia has at best a mixed performance across its overall innovation ecosystem. While there are notable bright spots, there are areas of deficiency and disconcerting trends. Figure 2 summarizes the findings from this broad view of Virginia's standing in innovation ecosystem capacities.

Figure 2: Virginia's Performance across Innovation Ecosystem Capacity Measures



In terms of strengths, there are many that help to define Virginia's stature in technology-based economic development. This includes:

- Virginia with $6.2 billion of research funding in 2015 across its multitude of federal intramural labs and FFRDCs stands four times higher than the national level relative to the size of its economy. This base of federal labs is a key driver of technology development in the state generating over 700 patent awards and applications over the 2014 to mid-2017 period.
- This strength in federal lab research also bolsters the state's industry research base. Nearly one-third of the state's industry research funding in 2015 was paid for by federal government research awards and contracts compared to just short of 8% nationally. Virginia also has a substantial base of federal Small Business Innovation Research grant awards, which funds feasibility assessment of new technologies and its further development based on commercialization plans. Virginia receives approximately $100 million annually, which is twice the national level relative to the size of the state's economy.
- Relative to Virginia's base of research, Virginia stands slightly ahead of the nation in its productivity of generating patents and in its quality of patents as reflected by a higher level of forward citations. This is not being generated by federal funding, which has been flat nationally and is growing slowly in Virginia as well, but reflects strong growth in business funding of research and a rising focus in Virginia on growing institutional and state & local funds for research.
- Virginia also is home to successful entrepreneurial companies able to attract venture capital investment at levels higher than the nation and noted among rankings of privately held, independent companies found on the Inc. 5000 listing for companies with strong growth in revenues over a three-year period – 270 companies from Virginia, or 5.4% of the national total, were recognized, including 7 among the top 100 fastest growing privately-held companies.
- A promising trend is that Virginia's universities, which have had a smaller presence relative to the size of Virginia's economy compared to university research nationally, are outpacing the growth of U.S. university research funding, including from businesses.
- The result of Virginia's standing in its research capacities, technology development and entrepreneurial energy is that it stands 34% more specialized in Advanced Industries that rely upon research and development and high skilled STEM workforce to compete based on innovation and technical know-how. This includes significantly higher levels of concentration than the nation in ship and boat building, computer systems design and related services, technical consulting services and polymer-based materials manufacturing. Altogether, Virginia has a specialized presence in 13 out 50 Advanced Industries identified by The Brookings Institution.

Still, the gaps facing Virginia are significant and may impact the ability of the state to drive technology commercialization at a level that can sustain advanced industry development.

- Industry research activity, particularly from own-sources, is lagging in Virginia in both its level and growth rates. The lackluster growth from own-source revenue combined with the declining levels of federal research funding led to Virginia declining in its industry research base by 4% while the across the nation industry research rose 21%.
- Led by industry research from all sources of funding being far below the national level – standing 54% lower than the nation relative to the size of the economy – translates into lower patent activity per economic output in Virginia.
- At the same time, there are troubling signs in sources of funding for industry technology development and entrepreneurial growth of innovation-based companies. SBIR funding, which Virginia has traditionally relied upon as an important source of funding for technology development and commercialization has fallen considerably due to cutbacks nationally. In venture capital investment, Virginia is not keeping pace with the growth nationally and appears to be lagging in funding at seed and early stage rounds of funding.
- While, Virginia's universities are picking up the pace in their own research activities and engagement with industry, as measured by business funding of research, the overall level of industry support continues to lag the nation. Meanwhile, there is mixed signs regarding technology transfer. Despite growing research budgets, the three largest research universities have not had commensurate increases in disclosures and patents, though licenses and start-ups are growing. The levels of technology transfer and commercialization, though, are average at best across Virginia's major research universities, standing on par in licenses and start-up activity. One area where university technology transfer lags seriously behind the nation is in revenue generation per license (whether from existing industry or new start-ups), which suggests the need to further advance university technologies to maximize their commercial value.
- Still, there is considerable base of activity by universities in Virginia to engage with industry that holds the potential to be part of the solution towards addressing the state's lackluster industry research and development activities. A review of companies jointly publishing and citing Virginia university patents demonstrates the world-class research capacities and attractiveness of these universities to many national firms.
- On the bottom-line measure of success in the growth of advanced industry job growth, Virginia is falling short. Virginia's advanced industries grew by a modest 3% compared to the 14% for the nation. While this may reflect declines in federal funding broadly on the Commonwealth's economy, it is translating into slower growth than nationally in some "hot" industries, including computer systems design and related services, management and technical consulting services, data processing, hosting and related services and engineering and architectural services.

C. Insights on Broad Capacities of Virginia in its Innovation Ecosystem

A snapshot of Virginia's capacities across its innovation ecosystem of R&D activity, technology commercialization, entrepreneurial development and advanced industry development suggests a sizable base of activity, including:

- $11.1 billion in total research funding in 2015
- 3,354 patents awarded to Virginia inventors in 2016
- $2.1 billion in venture capital expenditures for emerging companies in 2016
- 447,713 jobs in advanced industries in 2016

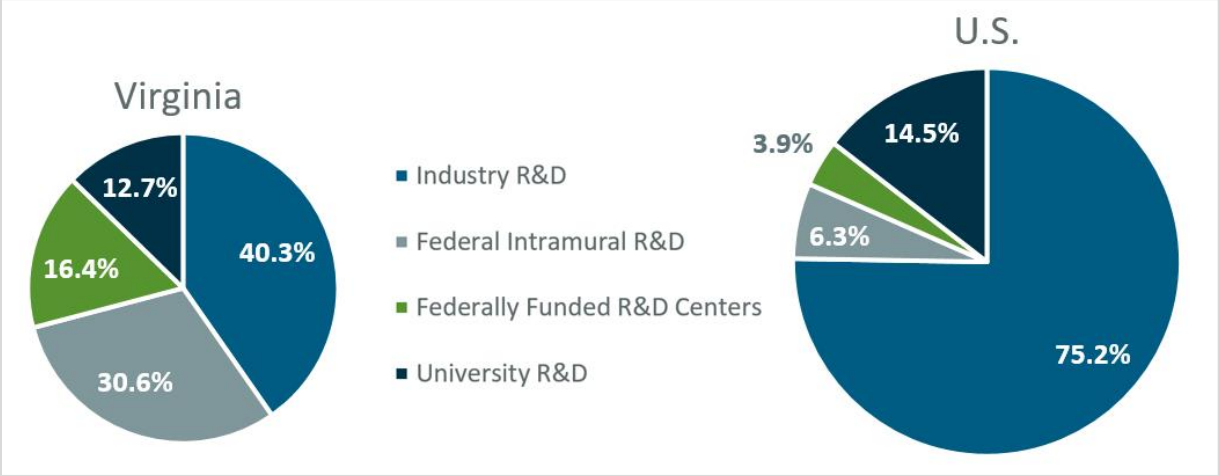
But a closer examination suggests the level of development and growth is quite distinct with specific areas of strengths and weaknesses relative to the nation.

Research Activity

The $11.1 billion in total research activity taking place in Virginia in 2015 includes $1.4 billion university research funding, $3.4 billion in federal intramural lab, $1.8 billion in federally funded R&D centers (FFRDC) and $4.5 billion in industry research funding – this turns out to be a very distinct mix of research activity.

Virginia stands out in its level of federal laboratory operations involving federal intramural labs operated by government agencies, such as NASA Langley and Naval Surface Warfare Center Dahlgren, and FFRDCs, a unique class of federally funded labs managed by outside strategic partners. Combined, federal intramural and FFRDC research activity reaches 47% of all research activity in Virginia compared to 10.2% nationally. This higher share of federal lab operations in Virginia would be expected to depress the shares of other sectors. In university research activity, Virginia's share is just off the national average at 12.7% compared to 14.5% nationally. But the share of industry research activity is quite low in Virginia at 40.3% compared to 75.2%.

Figure 3: Share of Total Research Funding by Sectors (University, Federal Labs and Industry), Virginia and U.S., 2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2010-2015 and TEConomy Partners analysis.

In assessing Virginia's level of research funding to that of the nation, it is important to normalize for the size of the state's economy compared to the nation, or what is commonly known as gross domestic product (GDP) that measures the economic output of goods and services produced.

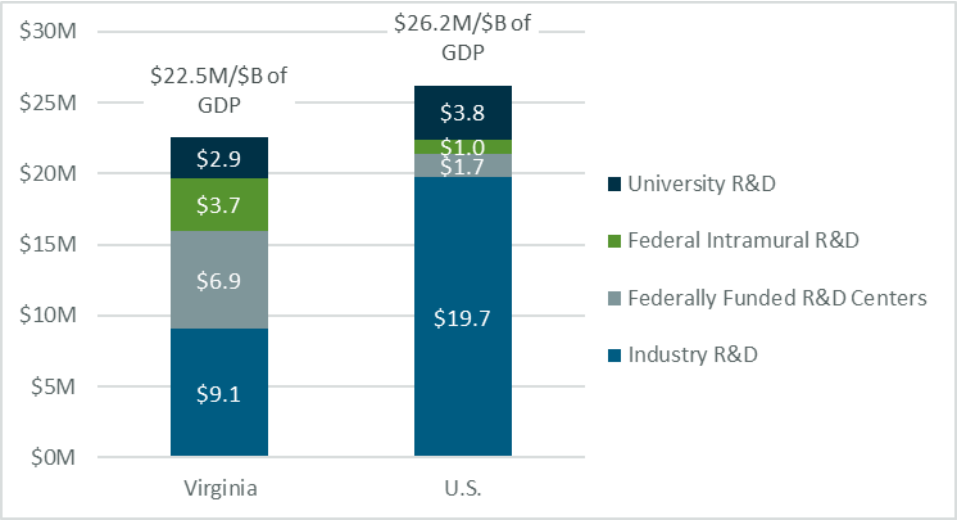
Relative to the size of its economy, the level of funding for research activities in Virginia stands lower than the nation and only exceeds the nation in its federal intramural labs and FFRDCs. The level of total research funding in Virginia relative to the size of economic activity stands at roughly $22.5 million per every $1 billion in GDP compared to $26.2 million for the nation in 2015 – so Virginia stands 14% lower than the national level of research activities across universities, federal labs and industry relative to the size of its economy. So, while Virginia makes up 2.7% of national economic activity, it accounts for only 2.4% of the nation's total research activity across universities, federal labs and industry.

As would be expected given the mix of research activity, Virginia well exceeds the nation in the level of federal intramural lab research and FFRDC activity. In 2015, Virginia had $6.9 million of federal intramural lab research funding per billion of GDP compared to $1.7 million for the nation in 2015 and $3.7 m of FFRDC funding per billion of GDP compared to $1.0 million nationally. Combined Virginia's federal lab activity reached $10.6 million – or nearly four times the national level after controlling for the size of economic activity.

Even though the share of university research funding in Virginia is not far below that of the nation, the lower total research base overall in Virginia translates into a 25% lower level relative to the size of the economy compared to the nation. Virginia's universities generated $2.9 million in research funding per billion GDP compared to $3.8 million for the nation in 2015.

Industry research funding is where Virginia is far below the national level, standing 54% lower than the nation. In 2015, Virginia generated $9.1 million in industry funding per $1 billion GDP compared to $19.7 million for the nation in 2015.

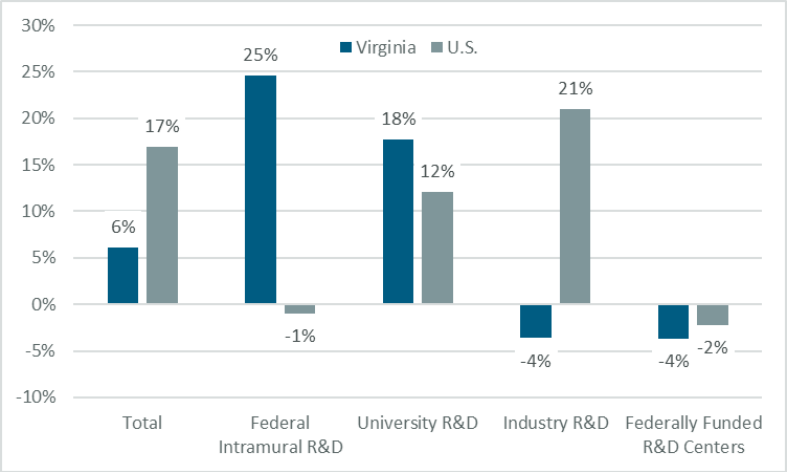
Figure 4: Level of Research Funding Per Billion of Gross Domestic Product, Total and Sectors, Virginia and U.S., 2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2010-2015 and TEConomy Partners analysis.

Growth of research activity in Virginia of 6.1% compares poorly to the more robust national growth of 16.9% from 2010 to 2015. Despite Virginia making strong gains in federal lab funding of 25% while the nation declined slightly and outpacing national growth in university research funding over the 2010-2015 period, the brisk growth of industry research funding found nationally did not take place in Virginia and FFRDC funding declined slightly more in Virginia than nationally.

Figure 5: Percentage Change in Research Funding by Sectors, Virginia and U.S., 2010-2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2010-2015 and TEConomy Partners analysis.

Technology Development and Commercialization

Once research activities lead to novel discoveries whether by university, federal lab or industry researchers, the next stage of innovation activities involves protecting the intellectual property, assessing its commercial value and advancing its development for commercial use. Several key measures are examined to assess the stage of technology development and commercialization, including patent activity, university technology transfer activities and use of Small Business Innovation Research Grants to further development.

Patent Activity

Intellectual property from research and development activities is most often protected as patents issued through governmental agencies, so that inventors can protect their product innovations from being replicated. Although there are other forms of intellectual property protection through copyrights, trademarks, and trade secrets, patents are among the most widely used form of protection of novel R&D-led inventions.

While there is no available database to measure the actual commercial value generated by patents, an excellent proxy measure of patent value and quality is whether it is cited by future patents issued by other inventors. These forward citations of a patent reflect the significance of its technological ideas and concepts as a basis upon which further intellectual property is generated, typically involving incremental improvements or new applications of the underlying technology.

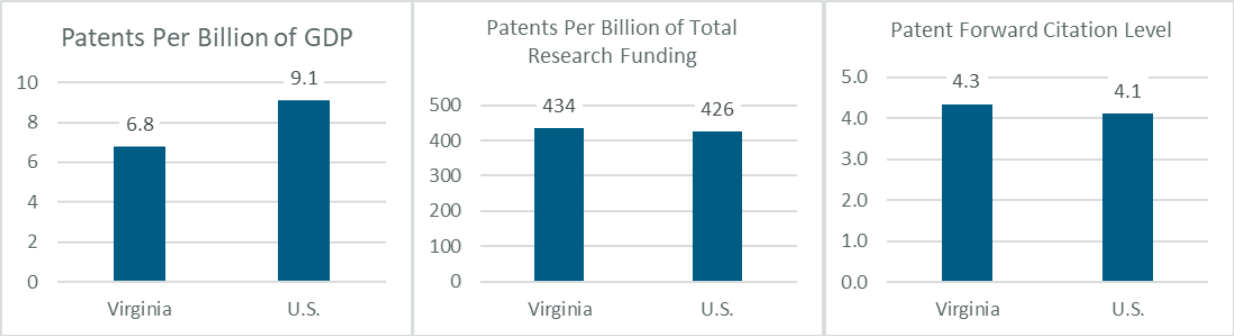
Virginia's performance in patent activity finds an overall lower level relative to the size of the economic activity in the state. This is not surprising given the significantly lower base of total research activity found in Virginia, but Virginia appears to hold its own in its productivity, quality and growth of patent activity compared to the nation.

The 3,354 patents issued to Virginia inventors in 2016 stood 25% below the level of the nation relative to the size of economic activity taking place in the state. Virginia generated 6.8 patents per billion dollars of GDP compared to 9.1 patents for the nation in 2016.

Still, relative to the size of the state R&D base – a measure of productivity in generating patents -- Virginia stands above the nation slightly above the nation in its level of patent activity. In 2015, Virginia generated 433.6 patents per billion of total research activity compared to 426.0 patents for the nation.

The quality of Virginia's patents stands slightly higher than the nation, having a 6% higher forward citation level. Over the 2010-2015 period, patents by Virginia inventors generated 4.34 citations per patent issued compared to 4.10 for the nation.

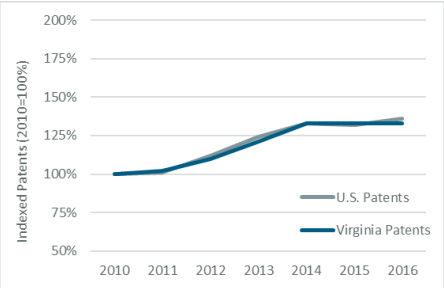
Figure 6: Measures of Patent Awards to Inventors, Virginia and U.S., 2015



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

Virginia is also holding its own in growth of patent activity over the 2010 to 2016 period. Virginia's level of patent activity rose 33.3% from 2010 to 2016 compared to the nation.

Figure 7: Growth Trends in Patents Invented, Virginia and U.S., 2010-2015



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

University Technology Transfer Activity

For universities and federal labs, the typical means for reaping the commercial benefits of research discoveries is through formal technology transfer activities involving not only generation of patents, but licensing of that intellectual property to existing companies or to new start-ups that are launched on the basis of that intellectual property.

A national database of technology transfer activity is maintained by the Association of University Technology Transfer Managers (AUTM). Over the 2010 to 2015 period only three Virginia universities reported consistently each year to AUTM – University of Virginia, Virginia Commonwealth University and Virginia Tech. Together these three research universities comprised 78% of all university research activity in 2015. These three universities also comprise 79% of all start-ups formed, 85% of licensing revenue generated, and 97% of the licenses executed according to the most recent annual plans submitted by universities to SCHEV.

Comparing these three major research universities to the national average of all universities finds that relative to the level of university research, Virginia stands higher in disclosures of new inventions and then comparable on levels of licenses issued and start-ups generated. Where the three large Virginia universities fall behind the nation is in the level of patents issued and gross license income generated, both relative to research activity and average per license.

Table 1: Technology Transfer Metrics for Virginia's Three Largest Research Universities Reporting to AUTM Compared to National Average of All Universities Reporting, Average 2010-2015, Per $10 million of University Research

Metric	Virginia Three Largest Research Universities	Average for All U.S. Universities Reporting to AUTM
Disclosures Per $10 million of Research	4.17 (2,475 total)	3.70
Patents Issued Per $10 million of Research	0.66 (393)	0.89
Licenses Issued Per $10 million of Research	1.01 (597)	1.02
Gross License Income Per $10 million of Research	$83,534 ($49.6 m)	$350,468
Average License Income	$83,089	$344,535
Start-ups Per $10 million of Research	0.13 (79 total)	0.13

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

The trends for technology transfer activity among the three largest universities in Virginia show an upward trend in start-ups formed and licenses executed, but decline in gross license revenue. This may be due to the growing focus on start-ups, but is hard to evaluate without further discussions. There is also significant variation from year-to-year in disclosures and patents awarded, with the most recent year being a lower performing one.

Table 2: Trends in Technology Transfer Activity for Three Largest Research Universities in Virginia, 2010-2015

Metric	2010	2011	2012	2013	2014	2015
Disclosures	388	396	430	439	437	385
Patents Issued	67	73	61	54	73	65
Licenses Issued	100	92	85	95	102	123
Gross License Income	$9.6 m	$9.9 m	$9.5 m	$5.8 m	$7.8 m	$7.0 m
Start-up Formed	9	9	12	13	14	22

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

Small Business Innovation Research Activity

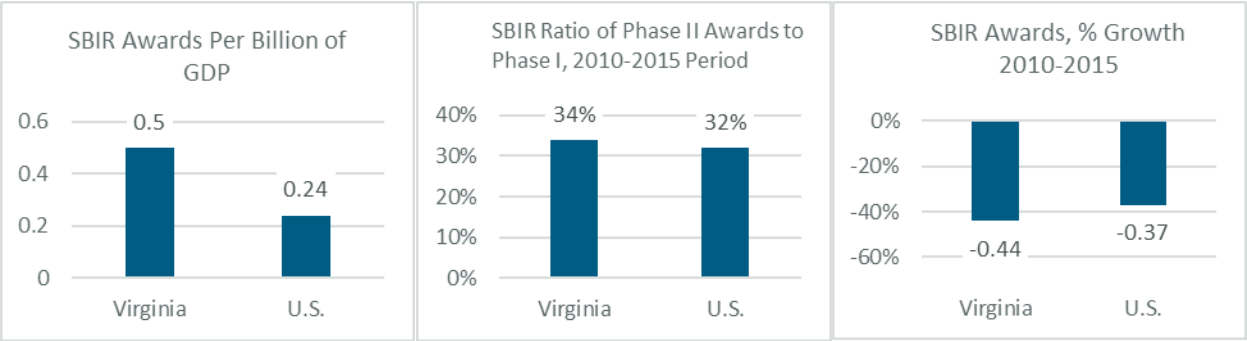
The federal Small Business Innovation Research (SBIR) program is another source of data on technology development and commercialization taking place in Virginia. The SBIR program encourages small businesses to undertake technology commercialization by requiring federal agencies with extramural R&D budgets that exceed $100 million to allocate 2.5 percent of their R&D budgets to the SBIR program. Each federal agency involved in the SBIR program then issues requests for proposals on topics reflecting their technology needs and interests, and competitively awards SBIR grants based on the technical merits and commercialization potential in a phased approach. There are two phases to the SBIR program, with Phase I focusing on technical merit and feasibility of a technology with typical funding of up to $150,000 and Phase II focusing on technology development and commercialization of the technology with typical funding of up to $1 million.

Virginia stands out in its level of SBIR awards, at roughly double the U.S. level compared to the size of the economy. Virginia had 0.5 SBIR awards per billion dollars of GDP in 2016 compared to just 0.24 SBIR awards for the nation. In 2016, Virginia received 245 SBIR awards and $99.1 million in SBIR funding.

Virginia also seems to convert their Phase I awards into Phase II at a slightly higher rate than the nation, since Virginia has a slightly higher share of Phase II awards over the 2010-2016 period than the nation (34% vs. 32%).

Over the 2010-2016 period, Virginia declined a steep 44% in the number of SBIR awards, while the nation fell by 37%, due to constraints on federal research funding.

Figure 8: Measures of SBIR Awards, Virginia and U.S., 2015 and 2010-2015



Source: TEConomy Partners Analysis of sbir.gov database.

Entrepreneurial Development

Of particular importance in an innovation ecosystem is the level and caliber of entrepreneurial development leading to new business start-ups. Starting with David Birch's work and validated by the Office of Advocacy of the U.S. Small Business Administration (SBA), and further refined by studies commissioned in recent years by the Kauffman Foundation and others, it is clear that entrepreneurship is a critical driver of innovation-led development. Among the specific measures used to assess Virginia's performance in entrepreneurial development are venture capital investments in high growth potential companies, presence of Virginia companies in the Inc. 5000 listing of high growth private companies and overall birth rates and job creation rates from births of new companies.

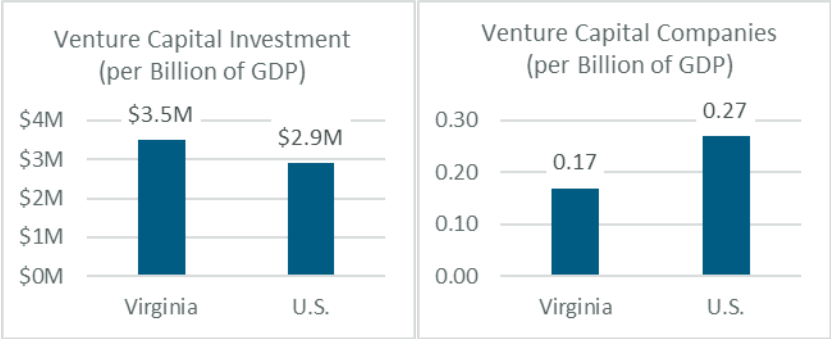
Venture Capital Activity

An important way to view to development of technology-based entrepreneurship is through funding by formal sources of venture capital. Venture capital represents formal equity investment by venture capital firms in emerging technology companies that offer high growth potential to generate sizable returns on that equity investment. The venture capital funding tracked by Thomson Reuters Venture One represents high growth potential emerging companies that have received formal funding from venture capital companies across the stages of funding.

It is best to consider venture capital investment over a period of time since it can vary significantly from year-to-year due to specific large deals that may take place in any one year. From 2010 to 2016, there were an average of nearly 76 companies in Virginia funded each year with an average of $1.6 billion annually or a total of just over $11 billion for the period. Compared to the nation, this translates into 1.7% share of national companies funded and 3.3% share of national venture capital investment over the period.

Relative to the size of Virginia's economy, Virginia's overall level of venture capital funding over the 2010 to 2016 period was significantly higher in investment dollars, with $3.5 million in venture capital investment per $1 billion in GDP compared to $2.9 billion nationally, but lower in companies receiving venture capital funding at 0.17 companies per $1 billion in GDP for Virginia compared to 0.27 companies nationally.

Figure 9: Level of Venture Capital Activity per Billion of Gross Domestic Product, Virginia and U.S., 2010 to 2016 Period

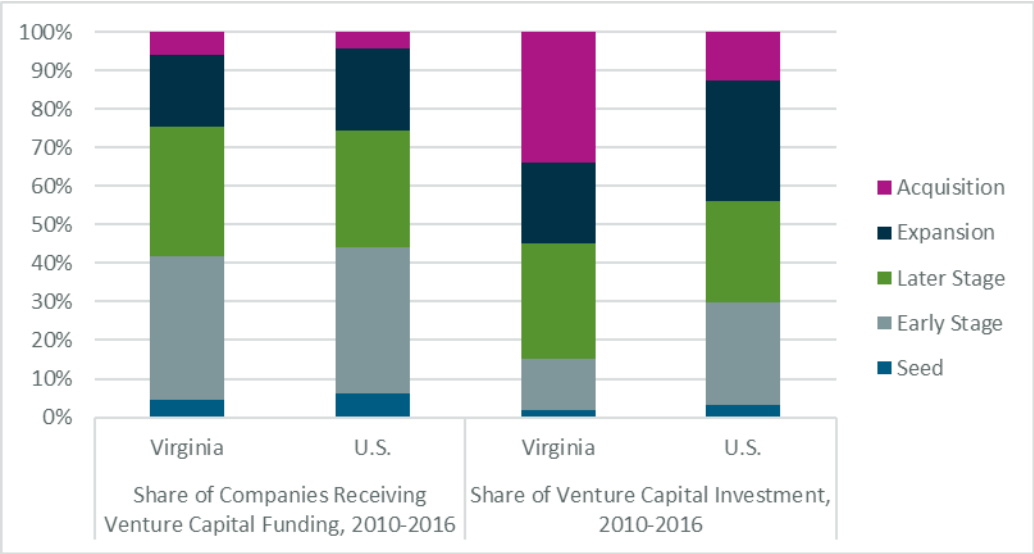


Source: TEConomy Partners analysis of Thomson ONE database.

This mixed performance in the level of venture capital investment and companies funded over the 2010-2016 period points to companies in Virginia companies receiving a substantially higher level of funding than nationally -- $20 million per company in Virginia vs. $10.8 million per company in the U.S., on average.

It also suggests that there may be significant differences in the stage of funding. Comparing Virginia to the U.S. over the 2010-2016 period by stage of funding finds that Virginia lags behind the nation at the earlier stages and outpaces the nation at the later stages, including acquisition. These differences are most pronounced in the level of investment, but still seen through the number of companies funded.

Figure 10: Venture Capital Companies and Investments by Investment Stage, Virginia and U.S., 2010 and 2015

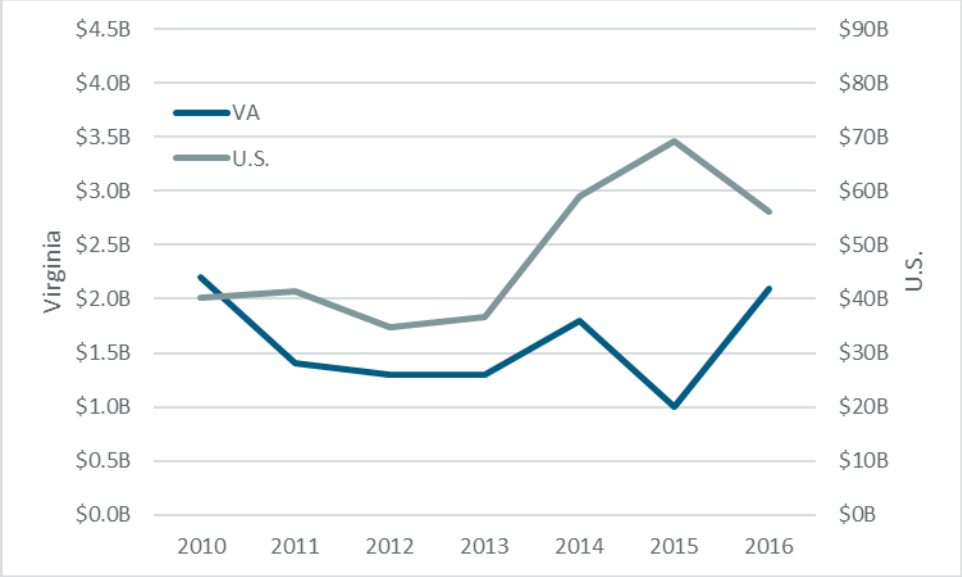


Source: TEConomy Partners analysis of Thomson ONE database. Note there are several small categories of other and public market funding not compared given small size.

In terms of trends, the number of companies funded each year has not had significant upward or downward trends for both Virginia and the U.S. and has tended to perform over a narrow range. For Virginia, the 2010-2016 average of 76 companies had a range from a high of 87 in 2012 and a low of 70 in 2013. For the U.S., the 2010-2016 average of 4,450 had a range from a high of 4,904 in 2015 and a low of 4,030 in 2010. For both Virginia and the US, 2016 was one of the lower years with 71 companies in Virginia and 4,193 companies in the U.S.

Comparing the trends in the level of funding from year-to-year, despite the greater variances at the state level it appears that Virginia is underperforming the nation. Virginia has been consistently well below the $2 million mark which it hit in 2010 and 2016, while the nation stands well above its 2010 level in recent years.

Figure 11: Trends in Venture Capital Investment, Virginia and U.S., 2010-2016



Source: TEConomy Partners analysis of Thomson ONE database.

Other Measures of Broader Entrepreneurial Activity

There are other measures of the state's entrepreneurial strength beyond venture capital that offer insights, though are not as strongly associated with technology innovation. One is the presence of Virginia privately-held, independent companies on the Inc. Magazine 5000 listing. This listing measures those companies with the higher percentage revenue growth over a three-year period, with at least at least $100,000 in revenues in the first year and at least $2 million in revenue in the third year.

Virginia stands out nationally in its presence in the Inc. 5000 with:

- **270 Virginia-based companies were recognized among the Inc. 5000, or 5.4% of all companies, while above the 2.7% share of the nation's economy that Virginia represents.**
- **7 Virginia-based companies were among the top 100 (see Table ?? below)**
- **63 Virginia-based companies were among the top 1000**

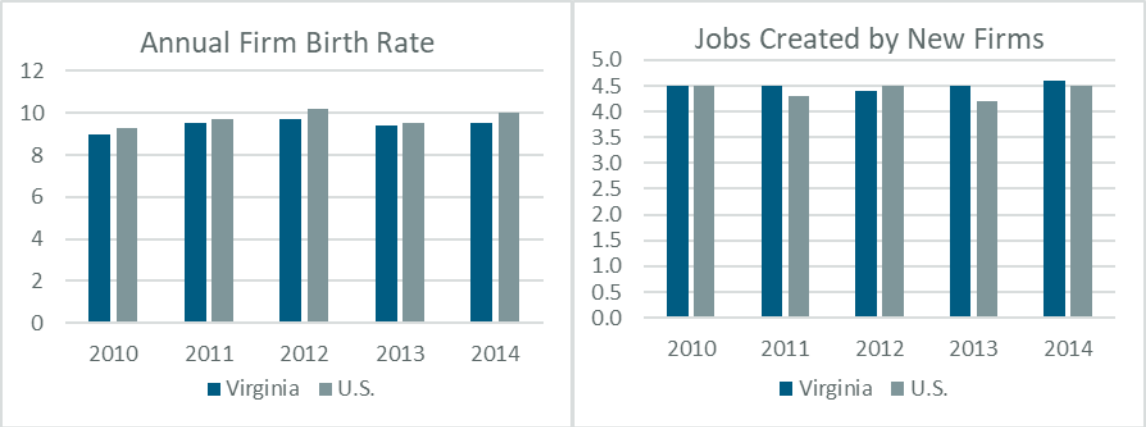
Table 3: Listing of Seven Virginia-based Companies among the Top 100 in the Inc. 5000

Company	Description	Inc. 5000 Rank	Year Founded	2016 Revenue	3-Year Revenue Growth	Total Jobs
DGC International	Offers intelligence, logistics, transportation, training and global operations support to the military and federal agencies	20	2010	$32.9 million	10,999%	10
TechAnax	Provides program management, network design and engineering, information assurance, IT, data center hosting, unified communications and other services to government agencies	29	2012	$15.1 million	9,119%	12
Interactive Government Holdings	Provides program management, grant management, administrative support, HR and veteran employment and reintegration services	36	2006	$15.3 million	7,024%	150
Enhanced Veterans Solutions	Provides IT and program management services to federal government agencies	38	2007	$8.7 million	6,866%	68
ByteCubed	Provides software development and technology services to companies and government agencies	46	2011	$31.7 million	6,469%	120
FedBiz IT Solutions	A hardware reseller and provider of networking, cyber security, enterprise computing and cloud systems services to the federal government	50	2011	$32.6 million	6,142%	12
Associated Veterans	Provides a wide range of services to government agencies, including business consulting, project and program management, legislative and policy research and analysis, records management and executive mentoring	64	2007	$7.8 million	5,334%	49

Source: Inc 5000 for 2017

In overall birth rate of new firms, however, Virginia is slightly below the U.S. average in recent years, as measured by the U.S. Census of Business Dynamics across all industries, not just those involved in new technology start-ups. The birth rate is measured as the number of new births given the total number of firms. Jobs created by firm births each year represents the average size of the new firms formed, and Virginia has been roughly on par with the nation in recent years.

Figure 12: Annual Rates of New Firm Birth and Job Creation, Virginia and U.S., 2010-2014



Source: U.S. Census of Business Dynamics

Advanced Industry Development

The ultimate aim of the innovation ecosystem is to generate industry growth through new product development, company start-ups and deployment of technology. The Brookings Institution has identified a set of 50 Advanced Industries ranging from manufacturing industries to energy industries to high-tech services from computer services to health applications. These Advanced Industries are characterized by:

- Deep involvement with technology research and development (R&D)
- Extensive use of STEM (science, technology, engineering, and math) workers

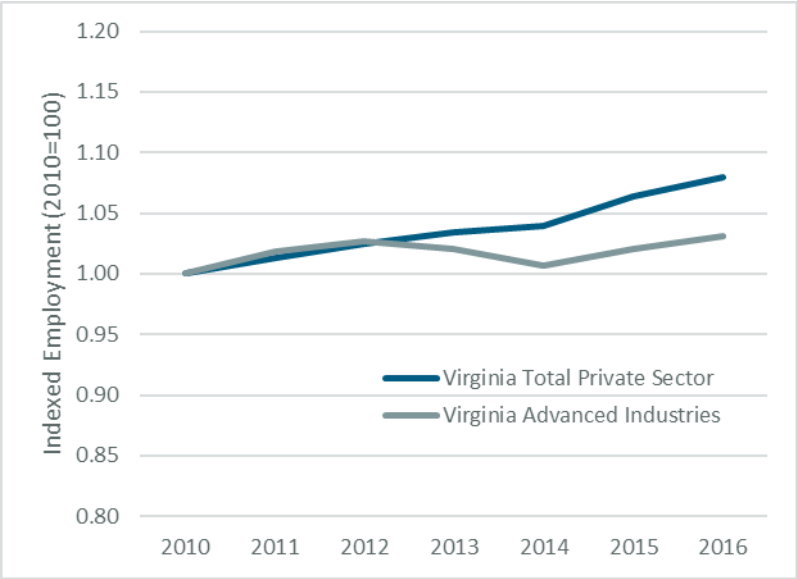
According to Brookings these Advanced Industries, "…. encompass the nation's highest-value economic activity. As such, these industries are the country's best shot at innovative, inclusive, and sustainable growth."[3]

Virginia stands out in its level of Advanced Industries. With 447,713 jobs, Virginia is 34% more specialized in its concentration of Advanced Industries than the nation.

[3] For more details see: Brookings Institution, *America's Advanced Industries: What They Are, Where They Are, And Why They Matter*, Brookings Advanced Industries Project, February 2015.

But Virginia is lagging in its growth of Advanced Industries since 2010. While the nation grew by 14% in Advanced Industry employment, Virginia grew a modest 3%, which was even well behind the state's growth in total private sector employment of 8%.

Figure 13: Total Private Sector vs. Advanced Industry Employment Trends for Virginia, 2010-2016



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

This mixed performance of strong specialization, but lagging growth is found across the leading Advanced Industries found in Virginia. In 13 out of the 50 Advanced Industries identified by the Brookings Institution, Virginia has a much higher level of specialization as measured by its employment concentration compared to the nation. Of these 13 leading Advanced Industries:

- Only two gained jobs at a rate faster than the nation from 2010-2016 -- railroad rolling stock manufacturing and other chemical product and preparation manufacturing
- Four gained jobs from 2010-2016, but at a level below the U.S. – medical and diagnostic laboratories, computer systems design and related services, management and technical consulting services, and data processing/hosting
- Eight either had no employment growth or declined in employment. Of these, five grew at the national level from 2010-2016, but did not gain jobs in Virginia – electrical equipment manufacturing, ship and boat building, resin/rubber/artificial fibers manufacturing, architectural and engineering services and scientific research and development services

Table 4: Advanced Industries in Virginia with a High Level of Industry Specialization and Their Employment Performance, 2010-2016

NAICS	Description	Virginia Jobs 2016	Virginia Level of Industry Specialization, 2016 (% Higher Concentration than Nation)	Virginia Job % Change, 2010-16	U.S. Job % Change, 2010-16
3365	Railroad rolling stock manufacturing	1,019	54%	85%	41%
6215	Medical and diagnostic laboratories	7,888	16%	13%	16%
5415	Computer systems design and related services	158,122	212%	13%	37%
5416	Management and technical consulting services	74,541	115%	10%	34%
5182	Data processing, hosting and related services	11,286	47%	7%	24%
3259	Other chemical product and preparation mfg.	3,810	83%	3%	-4%
3353	Electrical equipment manufacturing	5,874	65%	0%	3%
3366	Ship and boat building	23,706	591%	0%	8%
3252	Resin, rubber, and artificial fibers mfg.	4,841	103%	-8%	5%
5179	Other telecommunications	3,758	87%	-10%	-35%
5413	Architectural and engineering services	53,558	49%	-11%	10%
5417	Scientific research and development services	23,006	32%	-16%	10%
5174	Satellite telecommunications	308	54%	-35%	-33%

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

D. Sources of Funding Supporting Research Activity across University, Federal Lab and Industry

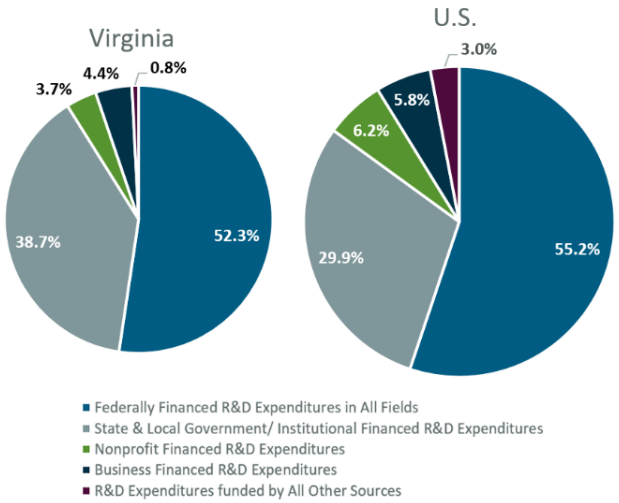
An important dynamic to understand as one considers the changing nature of research activity taking place in Virginia is the shifts taking place in the sources of funding driving university, federal lab and industry research activities. This section considers how Virginia compares to the U.S. average in the share of funding by different sources and the growth of different funding sources to industry.

University Sources of Research Funding

In university research activities, a variety of sources help to finance research activities. These include federal government, industry, state and local government, philanthropy and institutional funding. Due to changing accounting practices among Virginia institutions in how funding was reported between state and local government funding and institutional funding in 2014, it is necessary to combine state and local government funding with institutional funding as one category to compare nationally[4].

By far the largest source of funding for university research is from the federal government. Virginia stands comparable to the U.S. in the share of funding in 2015 and growth rates from 2010 to 2015. Nationally, just over 55% of all university research funding in 2015 comes from the federal government. Virginia is quite close in the share of university R&D coming from federal government sources at 52.3%. Similarly, both the nation and Virginia had meager growth in federal funding, with the nation growing by 1.1% and Virginia by 1.7% from 2010 to 2015, reflecting the limited growth of federal budgets.

Figure 14: Distribution of Total University Research Expenditures by Source of Funding, Va and U.S., 2015

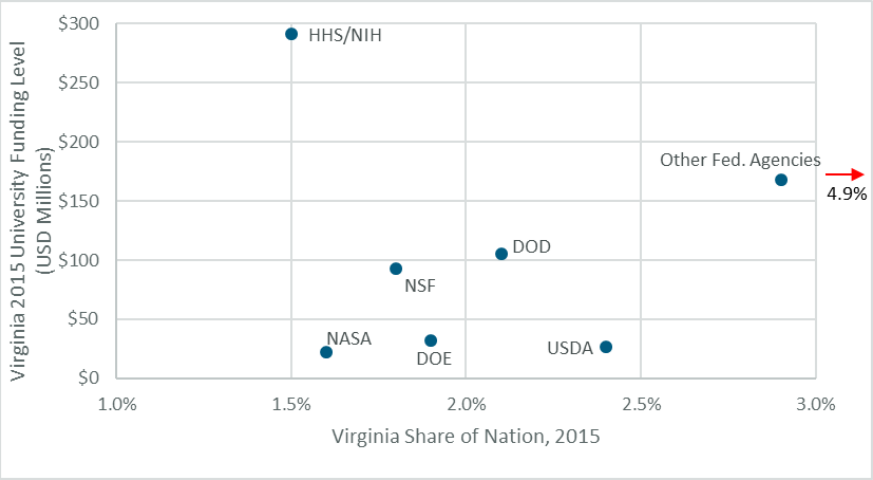


Source: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, FY 2010-2015 and TEConomy Partners analysis.

[4] Total state and local government research funding to universities from NSF's Higher Education Research and Development (HERD) expenditure reporting had a significant one-year decline from $143.8 million in 2013 to $72.6 million in 2014, while institutional funding to universities rose from $397.8 to $449.3 in that one year. A closer inspection suggests that this is largely due to a shift in how university expenditures were reported by Virginia Tech and not an actual decline in state and local expenditures. The TEConomy team will be exploring the nature of this change further with Virginia Tech.

Where Virginia stands apart from the nation is in the specific shares of federal funding from different agencies and growth of that funding. Overall, Virginia receive 1.9% of all federal funding of university research. Among major federal agencies funding university research, the two federal agencies that exceed this statewide average are the Department of Agriculture and the Department of Defense. Though the highest share for Virginia is in the "other" federal agency category, likely led by the Department of Transportation. While the Department of Health and Human Services, which includes NIH, provides the highest level of federal agency funding, it stands as the lowest share that Virginia receives of a major federal agency funding. Interestingly, Virginia also falls below its statewide average in funding from NASA, despite having a major NASA research center in the state.

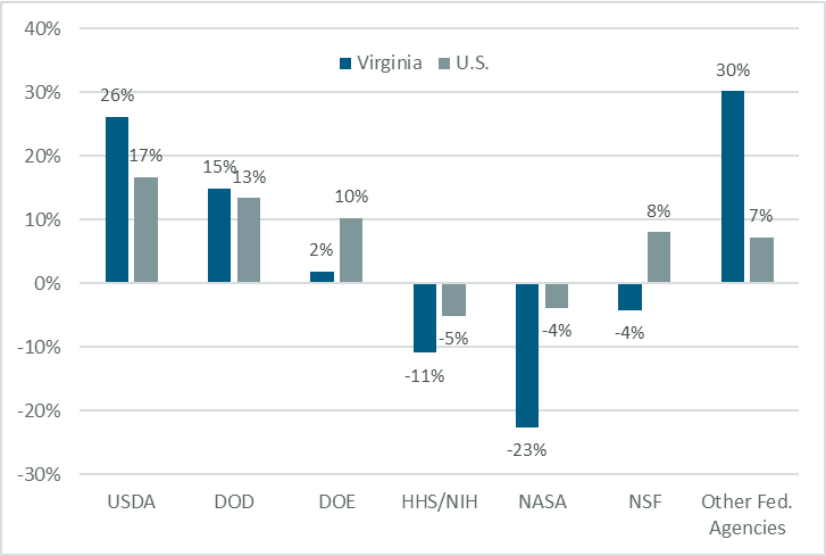
Figure 15: Virginia Share of Federal Agency National Funding to Universities, 2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2010-2015 and TEConomy Partners analysis.

While Virginia, along with the nation, barely grew in its federal funding from 2010 to 2015, there is considerable variation in the state's growth rates by specific federal agency. Virginia outpaced the growth of federal funding to universities from 2010 to 2015 for the Department of Defense, Department of Agriculture and Other Federal Department and Agencies, which likely reflects strong gains in Department of Transportation funding. Virginia declined more sharply than the nation in the Department of Health and Human Services (including NIH) and NASA funding to universities. Virginia universities also declined in National Science Foundation funding even though it grew across nation, and the state failed to keep pace with the Department of Energy funding to universities.

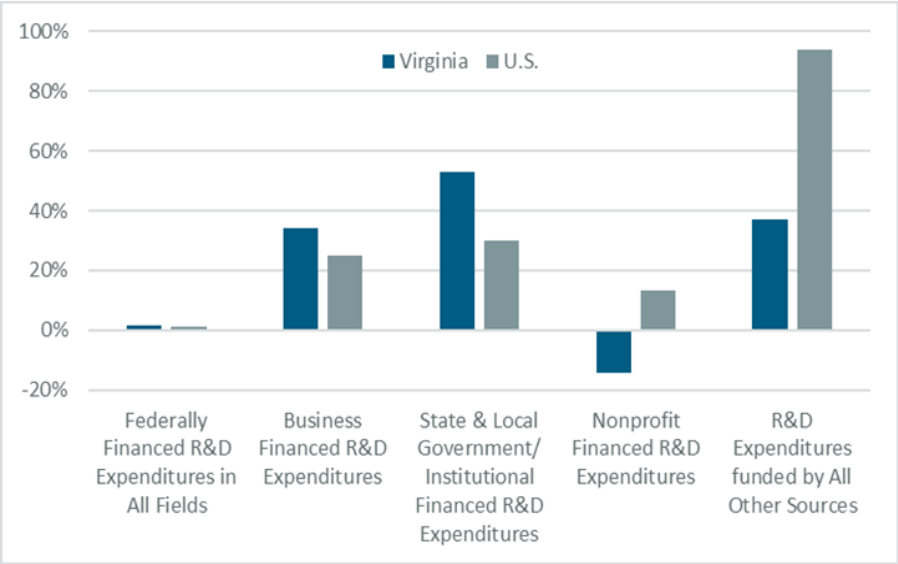
Figure 16: Virginia Share of Federal Agency National Funding to Universities, 2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2010-2015 and TEConomy Partners analysis.

The overall healthy growth of university research in Virginia that is outpacing the nation is being led by faster growth in business funding and in the combined area of state & local government/institutional funding. While federal funding growth barely grew in Virginia and the nation, Virginia's overall rise in university research is a reflection of considerable growth of 53% from 2010 to 2015 in state & local government/institutional funding and 34% growth in business funding, both of which are substantially higher than across the U.S. The only area of decline in university funding is by nonprofit/philanthropic sources.

Figure 17: Change in Sources of Total University Research Expenditures, Virginia and U.S., 2010-2015



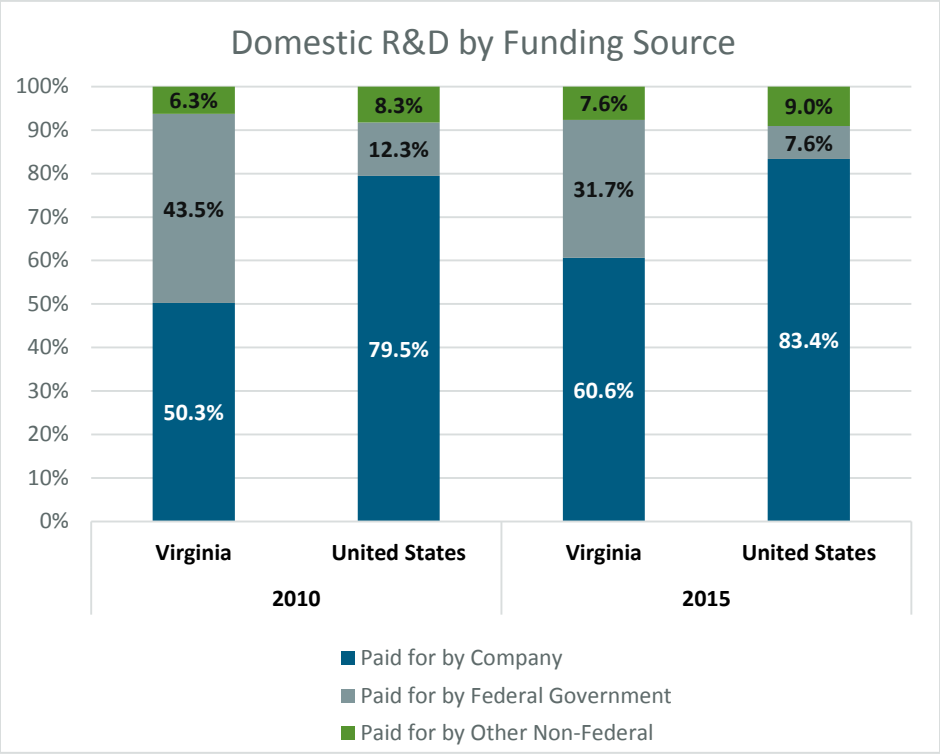
Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2010-2015 and TEConomy Partners analysis.

Sources of Industry Research and Development

Virginia's low level and declining base of industry research activity is an area of concern. Based on the NSF Business R&D and Innovation Survey, it is possible to learn more specifically the sources of industry research and development in three specific categories – own company resources, federal government paid R&D and other non-federal paid R&D, including other companies paying for contract research services. A look at these three sources of funding for industry research activity shows that Virginia is quite distinct from the nation.

Virginia has a much higher share of R&D paid by federal government than the nation, and lower shares of funding paid from own company resources and from other non-federal sources. In recent years, though, Virginia's industry research and development has shifted to a higher share of overall industry R&D.

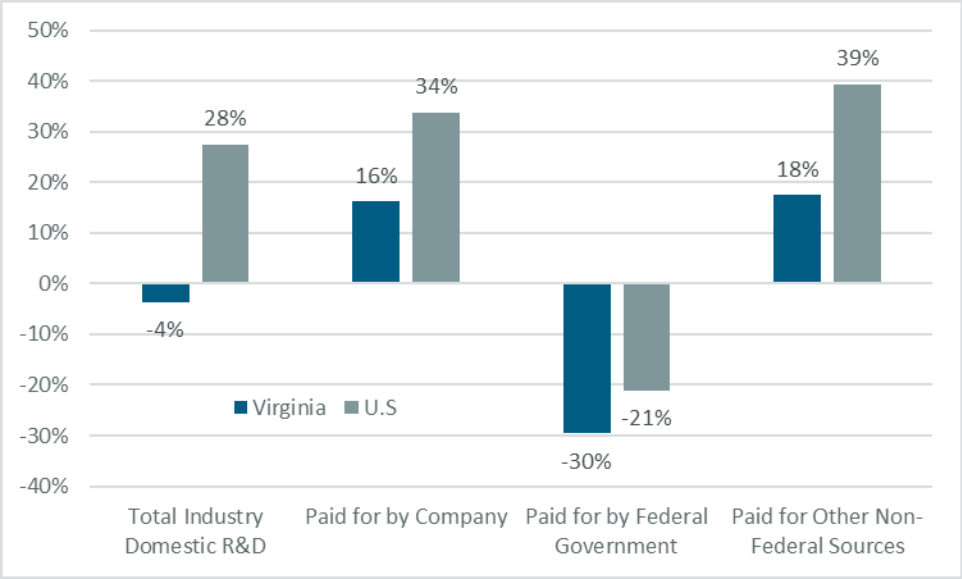
Figure 18: Share of Industry Research Funding by Source, Virginia and U.S., 2010 and 2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey FY 2010-2015 and TEConomy Partners analysis.

Unfortunately, the shift to a higher share of own company funding by Virginia is not a reflection of strong growth, but of declines in federal sources of funding for industry research and development. From 2010-2015, federal funding for industry research in Virginia fell by 29.6% compared to 21.1% nationally, while both own sources and non-federal sources of funding for industry research in Virginia grew at a slower pace than the nation.

Figure 19: Share of Industry Research Funding by Source, Virginia and U.S., 2010 and 2015

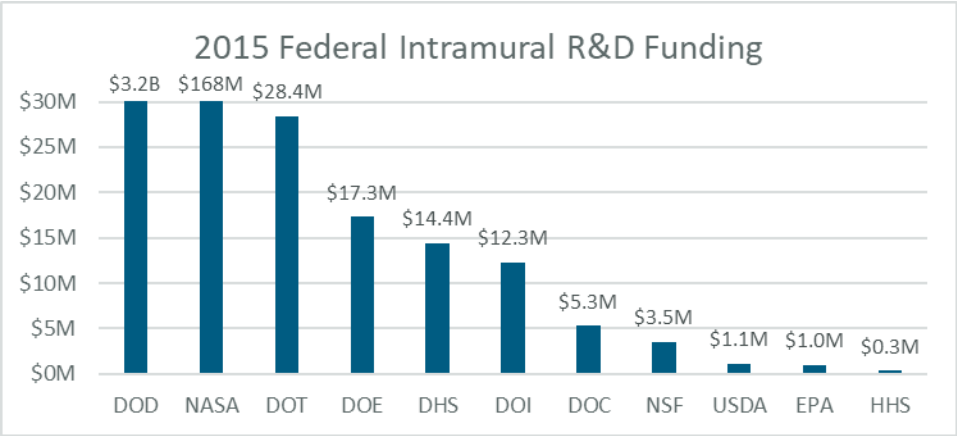


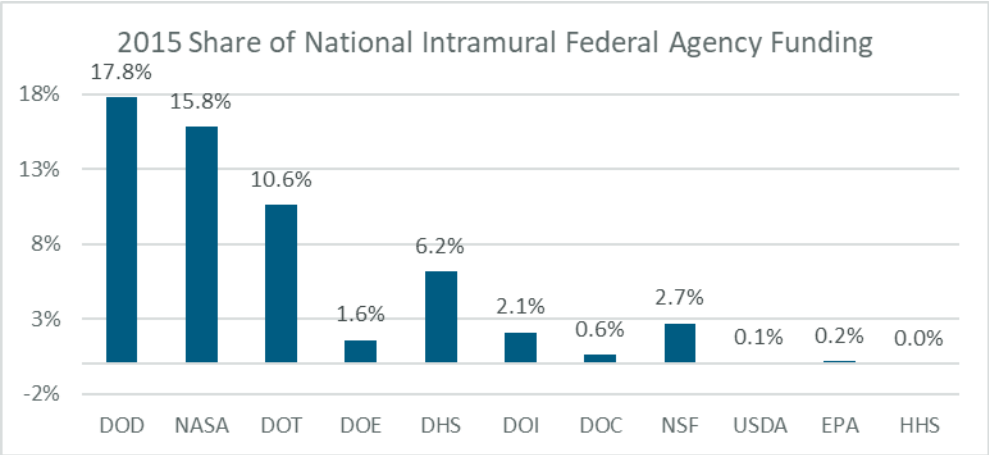
Source: National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey FY 2010-2015 and TEConomy Partners analysis.

Federal Intramural Lab and FFRDC Sources of Funding

The sources of federal lab intramural funding reflect which federal agencies have ongoing lab operations in Virginia. In 2015, the Department of Defense had both the highest dollar value of federal lab funding in Virginia as well as represented the highest share of that agency's intramural lab funding. The second and third highest in both the dollar value of funding and share of total agency intramural lab funding was for NASA and the Department of Transportation, respectively.

Figure 20: Federal Intramural Lab Funding by Federal Agency in Virginia, 2015 Funding Level and Share of Federal Agency's National Intramural Lab Funding

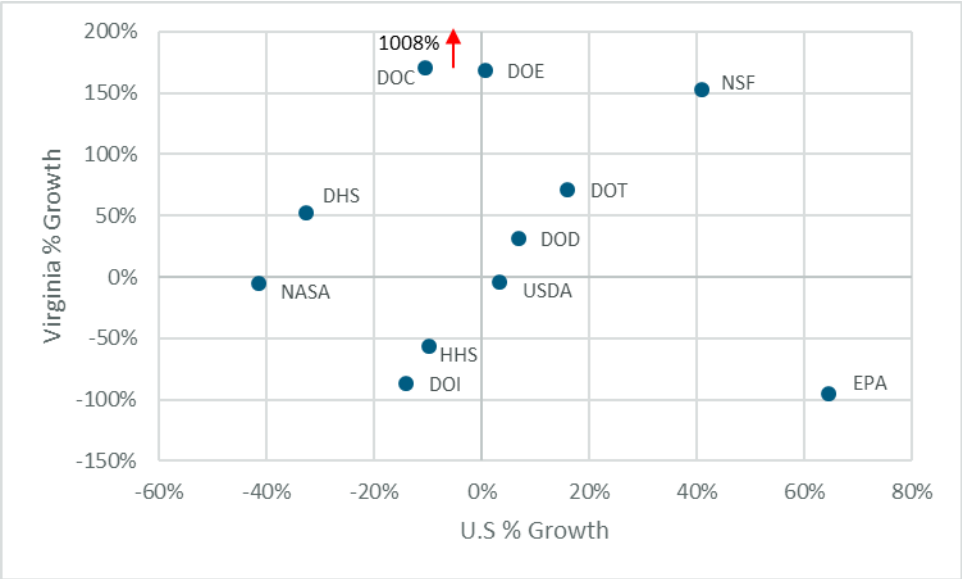




Source: National Science Foundation, National Center for Science and Engineering Statistics, FFRDC Research and Development Survey FY 2010-2015 and TEConomy Partners analysis.

In terms of growth of funding for federal intramural labs, the fastest growth in Virginia was found in three federal agencies with modest footprints of federal intramural labs in Virginia, Department of Commerce, Department of Homeland Security and Department of Energy, which all were either declining or flat nationally. Two of the large federal agencies with intramural labs in Virginia – the Department of Defense and the Department of Transportation -- grew strongly and outpaced national growth of intramural lab funding for those agencies. NASA declined in federal intramural lab funding in Virginia, but less than nationally.

Figure 21: Percentage Change in Federal Intramural Lab Funding by Federal Agency, Virginia and U.S., 2010-2015



Source: National Science Foundation, National Center for Science and Engineering Statistics, FFRDC Research and Development Survey FY 2010-2015 and TEConomy Partners analysis.

For FFRDC, it is possible to track funding by each of the eleven federally funded research and development centers (FFRDCs) located in Virginia. Nationally, there are 42 FFRDCs, so Virginia stands out in these types of specialized lab operations – and out of the nearly $19 billion of funding for FFRDCs, Virginia received $1.8 billion or roughly 10%.

These FFRDCs are a special class of federal intramural labs where the federal government contracts with an outside organization, often non-profits or universities, to serve as a strategic partner to the government, providing objective guidance in an environment free of conflicts of interest in areas of work in which the government cannot do as effectively. The FFRDC is required to work within the purpose, mission, general scope, or competency as assigned by the sponsoring agency. The FFRDC must not perform work that is otherwise performed by a for profit corporation. Most or all of the facilities are owned or funded by the Government, and the FFRDC has access to Government and supplier data, employees, and facilities beyond that common in a normal contractual relationship. An FFRDC can therefore function as an independent, trusted advisor and honest broker. The FFRDC is answerable only to the government customer and has no vested interest in particular technologies or solutions.

The period of 2010 to 2015 saw FFRDC funding decline in Virginia by 3.7% to reach a still sizable $1.8 billion in 2015 – in contrast to the strong growth of federal intramural lab activities. The highest funded FFRDC in Virginia by far is the National Security Engineering Center managed for the Department of Defense by MITRE. It comprises half of all the funding for FFRDCs in the state. The fastest growing FFRDC in Virginia is the Thomas Jefferson National Accelerator Facility managed for the Department of Energy by Jefferson Science Associates, LLC and the Homeland Security Systems Engineering and Development Institute managed for the Department of Homeland Security by MITRE.

Table 5: FFRDC 2015 Funding Level and Percentage Change, 2010-2015

FFRDC	2015 Funding Level	Percentage Change, 2010-2015
National Radio Astronomy Observatory	89,689	-34.8%
Thomas Jefferson National Accelerator Facility	128,036	41.5%
Center for Advanced Aviation System Development	155,696	4.0%
Center for Communications and Computing	56,478	-21.5%
Center for Enterprise Modernization	145,442	-14.7%
Center for Naval Analyses	80,358	-26.3%
Homeland Security Studies and Analysis Institute	16,965	-49.2%
Homeland Security Systems Engineering and Development Institute	77,176	31.4%
National Security Engineering Center	919,441	-0.6%
Systems and Analyses Center	157,645	1.1%
Judiciary Engineering and Modernization Center	4,318	-7.1%
Virginia All (11)	1,831,244	-3.7%

Source: National Science Foundation, National Center for Science and Engineering Statistics, FFRDC Research and Development Survey FY 2010-2015 and TEConomy Partners analysis.

E. Breadth and Depth of Connections across University and Federal Labs with Industry

Advancing the commercialization of technology advances generated through university and federal lab research activities requires close interaction with industry who understands the needs of commercial and government markets and has stronger expertise in advancing new product development from prototyping to scale-up manufacturing. More and more the translation of research discoveries into commercial products is recognized as a contact sport in which industry engagement is important at all stages, even in helping to inform the questions that drive basic research as well as in guiding the focus of more applied proof-of-concept and early prototyping activities that universities and federal labs undertake to demonstrate the feasibility of new discoveries as commercially viable innovations.

One way to gauge industry engagement with university research is through the level of research funding provided. As mentioned earlier in the sources of funding, Virginia overall lags the nation in the level of business funding of university research, but a closer examination shows that several research fields stand out.

Virginia universities received substantially more than its average of 4.1% of business funding for university research over the 2010-2015 period in the following areas:

- 10% in mechanical engineering
- 9.5% in aerospace engineering
- 8.9% in chemical engineering
- 7.7% in electrical engineering
- 6.8% in civil engineering
- 5.9% in medical sciences
- 5.3% in other environmental sciences

Still, as shown in Table 6, these research fields receiving a higher level of business funding for university research than Virginia's state-wide average still are just even with or lag behind the U.S. average in nearly every field, except electrical engineering where Virginia's 7.7% business funding of university research is slightly ahead of the U.S. average of 7.3%.

There were a few research fields in Virginia that did exceed the U.S. average for business funding of university research over the 2010 to 2015 period. Astronomy stood as the research field where Virginia outpaced the nation the most, with business funding standing at 4.7% compared to 1.9% nationally. Other physical sciences, involving multidisciplinary activities, also stood out for Virginia with 4.1% of research funding for Virginia universities coming from business sources compared to a national average of 3.1%. Chemistry was the only other research field in which Virginia had a slight edge on the U.S. average (4.4% vs 4.0%).

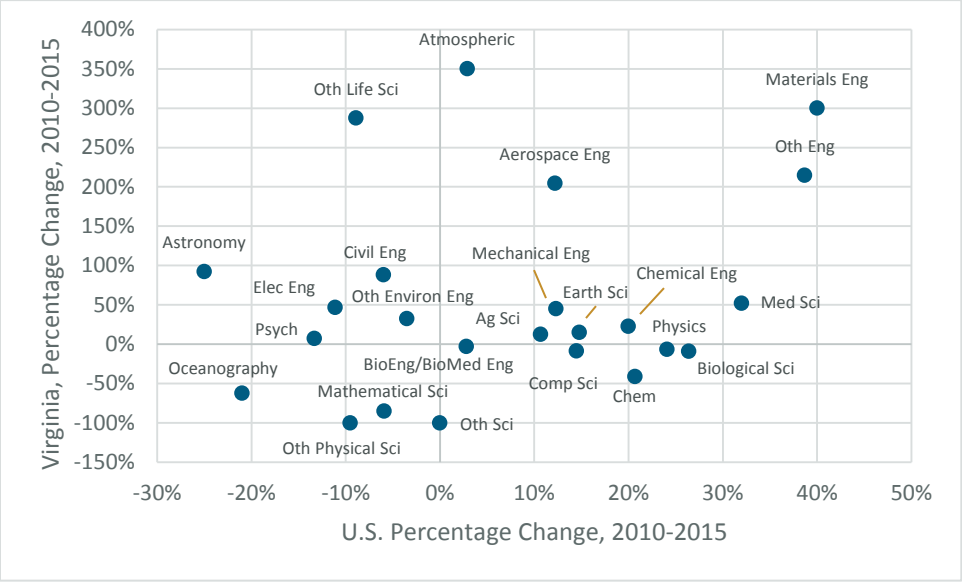
Table 6: Share of Business Funding for University Research over 2010-2015 Period, Virginia and U.S.

Research Field	Cumulative 2010-2015 Level of Business Funding ($ thousands)	VA Business Funding Share of Total R&D for Research Field	US Business Funding Share of Total R&D for Research Field
Mechanical Engineering	$37,900	10.0%	10.1%
Aerospace Engineering	$5,779	9.5%	9.8%
Chemical Engineering	$5,463	8.9%	15.4%
Electrical Engineering	$31,629	7.7%	7.3%
Civil Engineering	$25,925	6.8%	7.8%
Medical Sciences	$113,020	5.9%	6.8%
Other Environmental Sciences	$1,093	5.3%	5.4%
Astronomy	$2,107	4.7%	1.9%
Chemistry	$8,790	4.4%	4.0%
Agricultural Sciences	$27,571	4.3%	4.4%
Materials Engineering	$7,028	4.3%	14.5%
Other Physical Sciences	$393	4.1%	3.1%
Other Engineering	$10,287	3.6%	7.4%
Computer Sciences	$6,231	2.5%	4.5%
Earth Sciences	$2,161	2.5%	5.3%
Oceanography	$5,374	2.4%	3.6%
Other Life Sciences	$3,832	2.2%	2.7%
Bioengineering/Biomed Engineering	$2,415	1.7%	4.7%
Biological Sciences	$17,789	1.5%	3.0%
Physics	$3,136	1.3%	1.7%
Psychology	$1,827	1.1%	1.5%
Mathematical Sciences	$538	0.7%	1.4%
Atmospheric	$384	0.6%	2.0%
Other Sciences	$675	0.5%	7.1%
Total	$ 331,873	4.1%	5.3%

In terms of growth rates, the news is more positive for Virginia universities, since they outgrew the nation, rising 34% compared to 25%. Across research fields, a number of fields with a small to moderate base of funding grew rapidly such as Atmospheric Sciences, Aerospace Engineering, Materials Engineering, Astronomy and Other Life Sciences (nursing, public health, pharmaceutical, etc.). Among larger fields receiving business funding of more than $10 million cumulatively over the 2010-2015 period, strong gains were made by Other Engineering, Medical Sciences, Electrical Engineering, Mechanical Engineering and Civil Engineering.

There were several research fields in Virginia that declined in business funding for university research in Virginia, but grew nationally, including: Computer Sciences, Chemistry, Biological Sciences, Biomedical Engineering and Physics.

Figure 22: Percentage Growth of Business Funding for University Research by Field, 2010 to 2015, Virginia and U.S.



Source: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, FY 2010-2015 and TEConomy Partners analysis.

Another way to gauge industry-university/federal lab connections in research activities is through joint publications. There were 236 companies that had 10 or more publications with Virginia research institutions across universities and federal labs over the 2014 to mid-2017 period. These companies were quite diverse, with leading biopharmaceutical, nanoelectronics, defense companies, high-tech equipment and computer science companies. Among those companies with 50 or more joint publications with Virginia institutions were:

- Merck Company (79)
- Roche Holding (78)
- SRI International (66)
- Novartis (65)
- IMEC (63)
- General Electric (63)
- Sotera Defense Solutions (61)
- Leidos Inc (61)
- Nova Res Inc (60)
- Microsoft (60)
- Booz Allen Hamilton (56)
- Astrazeneca (56)
- Google Incorporated (53)
- Glaxosmithkline (50)

Moving into more translational research areas, the level of citations by industry of patents by universities and federal labs were not extensive, though they represent major corporations. Among those with 5 or more forward citations of university and federal lab patents invented in Virginia were:

- Cisco
- IBM
- General Electric
- AT&T
- Boeing
- Tyco Electronics
- Raytheon
- Honeywell
- Taiwan Semiconductor Manufacturing

What is interesting is that nearly all of the industry patents citing Virginia university and federal lab patents involved industry inventors located outside of Virginia. This suggests that in-state collaborations to advance technology are not strong in Virginia across industry and universities/federal labs.

For biomedical development, it is also possible to see the level of collaboration on clinical trials between Virginia universities and major medical centers through analyzing the database of clinical trials maintained through NIH National Library of Medicine's clinicaltrials.gov. Since many clinical trials simply involve having a site to recruit patients, what distinguishes a close industry-university/medical center connection is when a Virginia university/medical center is cited with industry as "collaborators" suggesting that they are each helping to guide the conduct of the overall clinical trial.

Virginia has a low level of university/medical center collaborations with industry. Among active clinical trials, out of 4,682 clinical trials started since 2010 with sites in Virginia, 81 or 1.7% represented collaborations of industry with university/medical centers in Virginia. This low level is generally found across disease areas, though 4% of the 470 metabolic/nutrition clinical trials with sites in Virginia and 2.7% of the 436 central nervous system clinical trials with sites in Virginia represented collaborations between industry and university/medical centers.

Where Virginia stands out is in the number of clinical trials in which universities/medical centers in Virginia are the principal investigator (or what is termed lead sponsor). Out of the 4682 clinical trials since 2010 with sites in Virginia, just over 10% were led by a Virginia principal investigator at a university or medical center in the state. Metabolic/nutrition clinical trials stand out with 17.7% led by a Virginia principal investigator and central nervous system clinical trials (436 since 2010) had 12.8% being led by a Virginia principal investigator.