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Assessment of Virginia's Research Assets:

Strategic Directions to Advance Innovation-Led Growth and High-Quality Job Creation across the Commonwealth

Prepared by: TEConomy Partners, LLC
Prepared for: State Council of Higher Education for Virginia
on behalf of the Virginia Research Investment Committee

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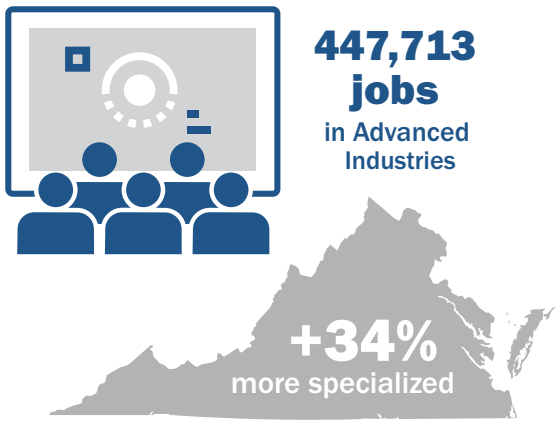
Executive Summary

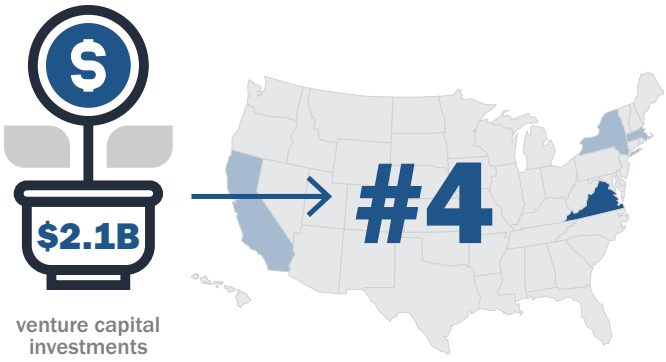
The economic stakes around innovation-led development are high. It has long been understood that innovation is a key driver of economic growth, high-quality jobs, and rising standards of living—explaining not only the differences in economic growth among nations, but also at the level of state and regional economies. As the 21st century unfolds, the performance bar for innovation-led development is rising with increasing globalization, the fast pace of technological change, and the growing strength of developing nations to compete for innovation-led development. So, no state can afford to become complacent. Past success offers a research and development (R&D) base to drive future growth opportunities; but, without a high-performing innovation ecosystem able to translate that R&D base into new products for existing companies and new start-ups, future success is not guaranteed.

Today, Virginia stands as one of the nation's leading innovation states. A quick snapshot of the most recent annual data available suggests the depth and breadth of Virginia's activities across its innovation ecosystem:

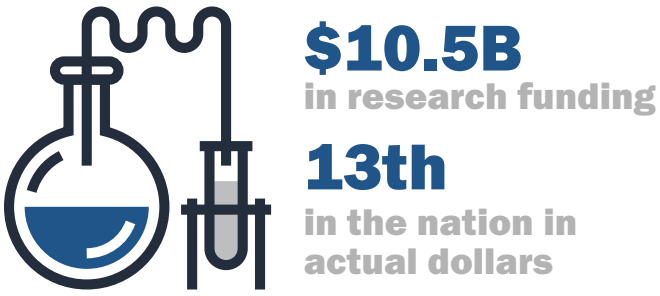
- ***Most important from an economic development perspective is that Virginia has a high concentration of jobs in advanced industries.*** With 447,713 jobs, Virginia is 34 percent more specialized in its concentration of advanced industries than the nation. These advanced industries, including 50 specific industries that range across manufacturing industries to computer and information services to energy industries to bioscience industries to engineering and commercial research services, are characterized by a deep involvement in advancing and deploying with R&D and with an extensive use of STEM (science, technology, engineering, and math) workers. For many, this is the ultimate measure of innovation development—creating jobs in industries innovating and deploying advanced technologies to compete.



- ***Virginia is also a national leader in entrepreneurial energy, with strong levels of venture capital investment and fast-growth companies that are bringing research and innovation to the market.*** With $2.1 billion in venture capital investments made in emerging companies in 2016, Virginia ranks fourth in the nation in venture capital investment per size of the state's economy. Only California, Massachusetts, and New York rank higher.[1] Venture capital investment is a hallmark of technology-based entrepreneurship in a state. 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. Plus, with 270 Virginia-based companies recognized as fast-growth privately held companies on the Inc. Magazine 5000 listing for 2016, Virginia comprises 5.4 percent of all companies, well above the 2.7 percent share of the nation's economy that Virginia represents. The Information Technology Innovation Foundation ranks Virginia first in the nation in fast-growth companies over the past two years as a share of total companies in the state based on Census data.[2]



- ***Supporting this base of advanced industries and entrepreneurial energy is a sizable base of R&D activities in Virginia, led by federal labs and federal funding.*** With $10.5 billion in total research funding in 2015, Virginia ranks 13th in the nation in actual dollars, though slips to 21st after adjusting for the size of the economy. Virginia, with $4.6 billion of research funding in 2015 across its multitude of federal intramural labs and federally funded R&D centers, 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 from 2014 to mid-2017. 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 with just short of 8 percent nationally.



Given this extensive base of activity, it is not surprising that Virginia has significant strategic growth opportunities emerging from its innovation-led base of activity (see text box).

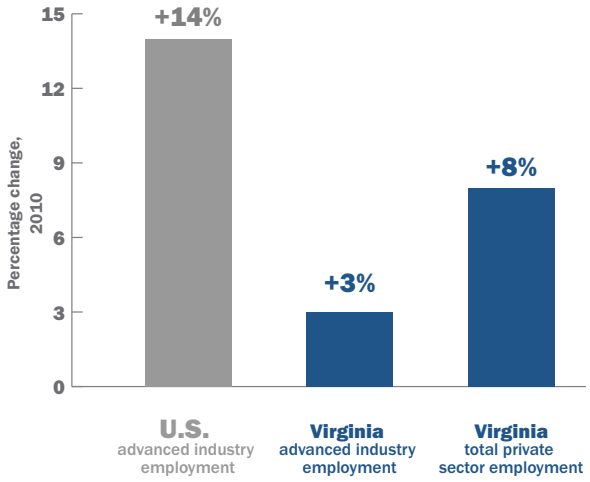
1 See Information Technology Innovation Foundation, 2017 State New Economy Index, for full rankings of venture capital per state gross domestic product, page 50.
2 Ibid., page 33.

But, Virginia's innovation ecosystem is underperforming since the current economic recovery began in 2010. A significant divergence between the overall innovation capacity found in Virginia and the trends and dynamics in innovation has emerged. The signs of lagging performance in Virginia's innovation ecosystem are unmistakable:

- ***Advanced industry growth is lagging the nation.*** While the nation grew by 14 percent in advanced industry employment, Virginia grew a modest 3 percent, which was even well behind the state's growth in total private sector employment of 8 percent (Figure ES-1).

  This lagging growth is not centered in one or two advanced industries, but is prevalent across most of the leading advanced industries found in Virginia.

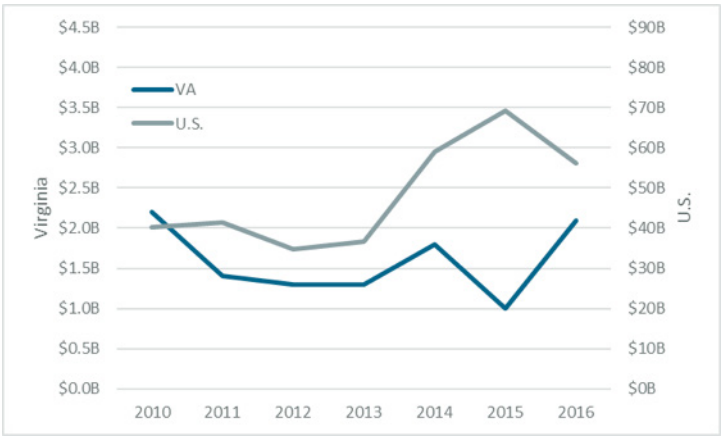
Figure ES-1. Employment Growth Comparisons, U.S. Advanced Industries, Virginia Advanced Industries, and Virginia Total Private Sector Industries, 2010–2016



Source: TEConomy Partners' analysis of U.S. Bureau of Labor Statistics, Quarterly Census of Employment and Wages data; enhanced file from IMPLAN Group.

- ***Over the 2010 to 2016 period, venture capital has flattened out in Virginia, while rising nationally.*** Virginia has been consistently well below the $2 billion mark, which it hit in 2010 and 2016, while the nation stands well above its 2010 level in recent years (Figure ES-4).

Figure ES-4. Trends in Venture Capital Investment, Virginia and the United States, 2010–2016



Source: TEConomy Partners' analysis of Thomson ONE database.

Identification of Strategic Growth Opportunities for Innovation-Led Development in Virginia

To assess what strategic growth opportunities are found in Virginia to lead statewide growth, an extensive and rigorous analysis of industry-led patent innovation networks and research publications clusters was undertaken. This analysis identified 14 innovation platforms where Virginia has a critical mass in its technology expertise, or core competencies, across its industries and research institutions, involving universities, federal labs, and nonprofit organizations, to position the state for future innovation-led growth in targeted markets.

A line-of-sight analysis then considered the depth, excellence, and alignment of innovation platforms across both industry and research institutional core competencies to serve as strategic growth opportunities where Virginia has the know-how and capacity to grow in the future. Figure ES-2 presents the overall approach and the specific metrics used in the line-of-sight assessment.

Consulting with industry leaders and regional technology councils and further deliberating on the mix of potential innovation platforms and their market potentials led to the identification of four strategic growth opportunities that best align research and industry innovation strengths with growing market opportunities for Virginia:

- Cyber and Cyber-Physical Security
- Integrated Networking, Communications, and Data Analytics
- System of Systems (SoSE) Engineering Solutions
- Life Sciences.

These strategic growth opportunities represent cross-cutting, multidisciplinary capacities that set out distinct areas where Virginia has the ability to leverage its collective research and industry innovation assets to drive economic growth and to focus resources and aggregate innovation activity into meaningful initiatives. Figure ES-3 shows the comprehensive way in which the strategic growth opportunities incorporate multiple innovation platforms within the scope of their applications and market opportunities. Detailed profiles and recommended development pathways for each growth opportunity are laid out in the sections below.

Figure ES-2. Line-of-Sight Approach for Identifying Strategic Growth Platforms for Virginia

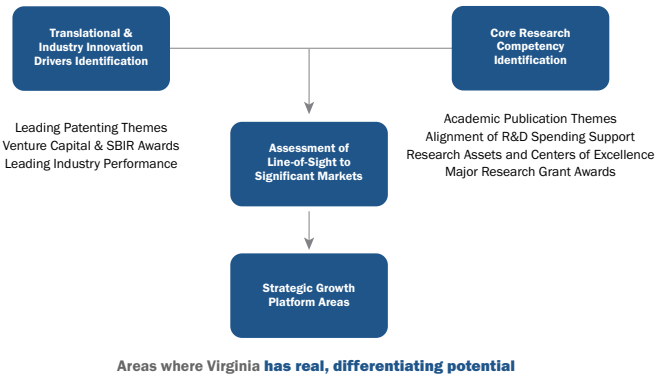
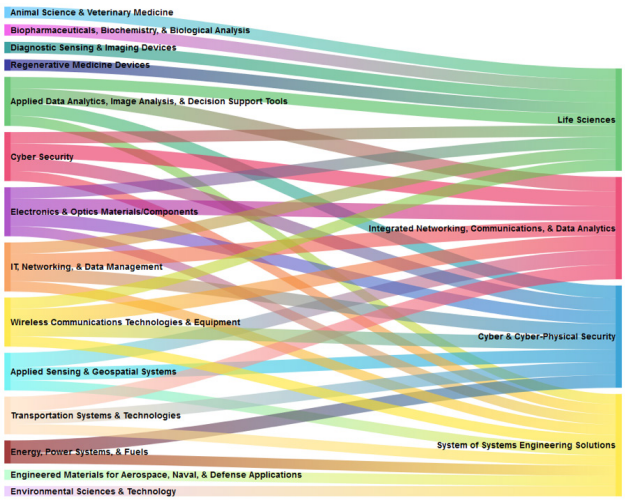


Figure ES-3. Cross-Cutting Relationships between Virginia Innovation Platforms and Virginia Strategic Growth Opportunity Areas



- ***Virginia declined in overall research funding from 2010 to 2015, while the nation grew.*** In overall research funding, across industry, federal labs, and universities, Virginia fell by 6.3 percent or nearly $500 million from 2010 to 2015, while nationally total R&D activity rose a healthy 14.5 percent. Virginia was one of only 12 states and the District of Columbia that recorded declines in overall research funding. The other states recording declines in overall research funding, though, were generally small research states, with the notable exceptions of Minnesota and Missouri. Other leading states in overall research funding recorded strong growth, including California (+54 percent), Massachusetts (+42 percent), Michigan (+29 percent), Texas (+57 percent), and Maryland (+33 percent)—meaning Virginia is losing ground to top states.

  Looking across the sectors of research activity, the largest decline for Virginia was found in its federal intramural lab (-20 percent) and federally funded R&D centers (-3.7 percent). But, industry R&D in Virginia also declined a significant 3.6 percent, while growing robustly nationally, due to its dependence on federal research funding contracts.

Without a doubt, Virginia's slowdown in innovation activity, impacting not only research but also advanced industry employment, can be traced to declining levels of federal research support in the state. Still, closer review reveals underlying challenges facing Virginia's innovation ecosystem that need to be addressed to unleash Virginia's potential for innovation-led development. The concern is that, even if federal research activity picks up, Virginia will still underperform in its potential growth from translating its research assets into tangible economic growth.

These underlying challenges include the following:

- ***Addressing the low levels and lagging growth of industry R&D from own-company sources that focus on developing new products and services.*** Overall, the level of industry R&D activity in Virginia is less than half that of the nation relative to the size of its economy. The reason for Virginia's weak level of industry R&D is its significantly lower level of own-funding by companies for R&D. Virginia is just a third of the U.S. level relative to the size of Virginia's economy in the amount its companies directly fund from their own revenues for research. Virginia has $652,000 of own-source company funding per $1 billion of gross domestic product, compared with $2,028,000 nationally.

  Virginia's higher federal funding of industry R&D cannot make up for this significant difference since the vast funding nationally for industry R&D is paid for by companies. More importantly, the nature of federal R&D funding is unlike company R&D funding. Federal research funding pays for contract research services to assist federal agencies in their missions, and so does not directly drive new commercial products. Company R&D funding from their own revenues pays for advancing new products and processes that go on to generate new revenues and more competitive companies that then drive job growth.

- ***Strengthening university capacities in technology transfer and commercialization, while growing its research base with more team-based, translational research centers.*** Virginia's top research universities

are active in university technology transfer, with policies consistent with national best practices and performance generally at or slightly above the national average and showing upward trends. Still, there are substantial opportunities for improvement. A separate assessment of university technology practices sets out 34 recommendations for improving technology transfer and commercialization, with its main areas of focus on advancing translational research and commercialization practices. The types of improvements that can strengthen Virginia's university technology transfer and commercialization include providing more technical and market expertise input into how inventions are assessed before patent decisions are made; undertaking more invention lead prospecting with proven entrepreneurs walking the halls; increasing the access to proof-of-concept projects for de-risking university technologies; creating more streamlined templates and transparency in deal-terms; and better connecting with entrepreneurs, venture investors, and other stakeholders as the commercialization process unfolds and new start-ups are formed.

However, another part of the equation on raising results from technology transfer and commercialization needs to be considered—the size of university research activities in Virginia. Virginia is 25 percent below the national level of university research relative to the size of the economy compared with the nation. In 2015, Virginia's universities generated $2.9 million in research funding per billion GDP, compared with $3.8 million for the nation. Virginia universities need to set their sights on being more competitive for federally funded research centers. These federally funded university research centers offer the ability to create the capacities needed for more translational research that is likely to create new IP and engage industry partners, involving team-based, multidisciplinary research able to address solutions, with large-scale shared-use laboratories able to support industry users

- ***Bridging the disconnect between university research and Virginia-based company innovation.*** This assessment of the innovation ecosystem points to the significant gaps in collaboration and engagement between Virginia universities and industry. Industry-sponsored research across Virginia universities at 4.4 percent of total university research funding is well below the national average of 5.8 percent. This lagging level of industry-university research collaborations, though, does not account for the amount of activity taking place with Virginia-based companies. A closer examination raises even greater concerns that the lower levels of industry collaboration with universities overall stem from the lack of close relationships with Virginia industry:

    - In university patents developed with industry funding (a window into who is sponsoring university research), out-of-state companies dominate, with 35 of 40 patents involving companies from out of state.

    - In citations of university patents (a measure of how closely university innovations are linked to follow-on industry innovations), 303 of 327 industry citations of Virginia university patents were by industry inventors located outside of Virginia. Similarly, for Virginia invented patents associated with federal laboratories/ agencies, 417 of 466 industry citations were by industry inventors located outside of Virginia.

- In licensing of university patents, out-of-state companies drive licensing activity from Virginia universities, with 108 of 137 licenses issued in fiscal year 2017 going to out-of-state companies.

A challenge for growing strong industry-university partnerships is the geographic mismatch of anchor research institutions, located across the state, and the strong concentration of industry innovation, as measured by patents, in northern Virginia. The implications of having such a diverse geographic footprint suggest that Virginia needs to create statewide linkages to maximize its growth potentials for innovation and incorporate strategic thinking to better geographically connect university activity with industry to realize its growth potential in each area.

- ***Shoring up Virginia's entrepreneurial development system to generate more shots on goal and high-growth companies.*** Discussions with the regional technology councils and industry executives reveal distinct innovation needs within each region of Virginia as well as the need to ensure that each region has the capacity to collaborate with its anchor research institutions in advancing innovation-led development.

  For Virginia, there are clear concerns about the ability to generate early-stage, high-growth companies. In terms of trends, the number of companies funded in Virginia receiving formal venture capital has remained relatively flat. For 2010–2016, Virginia had an average of 76 companies, with a high of 87 in 2012 and a low of 70 in 2013. While this is not much different than the pattern nationally, it is disconcerting against the backdrop of lagging growth in venture capital funding. And perhaps Virginia differs from the nation most critically in its low share of venture investment going into early-stage rounds of funding. An examination across the strategic growth opportunities finds that venture capital investment in Virginia is highly concentrated and not finding its way to those regions where the anchor research institutions are based.

Going forward, business as usual will not work for Virginia to address its innovation challenges. A new strategic direction is needed.

Virginia's underperformance in its innovation ecosystem and the underlying gaps identified suggest that, despite having strengths in R&D core competencies with a line-of-sight to strategic growth opportunities, Virginia has uncertain prospects of realizing that growth. Only by addressing its underlying gaps head-on, with statewide approaches, can Virginia right the ship and regain its course toward innovation-led development.

Figure ES-5. Summary of Virginia's Situation in Innovation-Led Development

Virginia has a sizable base of innovation-led assets	But Virginia has not been performing well in innovation-led development through the recent period of economic growth	Business as usual will not work. Virginia needs a new way forward in innovation-led development.
$10.5 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 – 34% more specialized than the nation	Total R&D funding lower in 2015 than 2010 – Virginia declined by 6.3% while U.S. grew by more than 17% Venture capital growth not keeping pace and lower share of seed and early stage capital investments Advanced industry growth well off the national pace, including for nearly all of Virginia's 13 major advanced industries	Better position Virginia industry for commercial product –led innovation in strategic growth opportunity areas Strengthen university translational research and development capacity Bridge the disconnect between university research and Virginia-based company innovation Shore up Virginia's regionally-based innovation capacities to generate more start-ups and advance high-growth companies

Addressing the four underlying innovation ecosystem challenges, with a focus around the strategic growth opportunities, offers the Commonwealth of Virginia a comprehensive and reinforcing approach to address its underperforming innovation ecosystem and draws upon best practices in innovation-led development from other states to help in informing and designing effective actions to be taken (Figure ES-5).

The strategy provides a cohesive and comprehensive investment framework for the Virginia Research Investment Fund (VRIF), whose primary mandate is to focus on innovative and collaborative research, development, and commercialization projects and programs with a high potential for economic development and job creation opportunities. However, the challenges presented by Virginia's innovation ecosystem expand beyond the mandate of VRIF. Therefore, to ensure success, the strategy also seeks to inform broader state efforts to advance innovation-led development.

Specific actions have been identified and designed for the use of VRIF in four strategic areas:

- **Strategy One:** Pursue the strategic growth opportunities through public-private collaborations in advancing translational research capacities.
- **Strategy Two:** Strength university technology transfer and commercialization capacity.
- **Strategy Three:** Bridge the disconnect between university research and Virginia-based company innovation.
- **Strategy Four:** Shore up Virginia's regionally based innovation capacities to generate more start-ups and advance high-growth companies.

The strategic directions in this report set out a number of specific baseline actions consistent with the current funding levels for VRIF. The 2018–2019 biennial budget recently proposed by Governor Terry McAuliffe sets an annual budget of $8 million for VRIF.

These baseline actions cover the first three strategic areas set out above involving advancing translational research capacities in the strategic growth opportunity areas in concert with industry engagement, strengthening university technology transfer and commercialization capacity, and bridging the disconnect between university research and Virginia-based company innovation. The fourth area of activity focused on shoring up regional entrepreneurial and innovation ecosystems is beyond the reach of VRIF's baseline funding, but it is a critical complement to the ability of Virginia's regions to leverage the growth potential from their anchor research institutions.

These baseline actions also include ways, when appropriate, to better coordinate with ongoing innovation activities that Virginia supports, including the Virginia Biosciences Health Research Corporation, Commonwealth Health Research Board, and the Center for Innovative Technology. Together, these three programs provide approximately $9 million to $10 million across a broader range of activities than envisioned for the baseline actions for VRIF, including basic research, entrepreneurial company development/investment, and technology commercialization. What distinguishes VRIF from these other ongoing, though undersized, innovation efforts are its focus on the following:

- Raising university translational research and commercialization capacities, connecting it more systematically with market-driven processes and focusing it on value creation for economic development in the Commonwealth.
- Comprehensively bridging the disconnect between industry and university research collaborations across translational research, applied research, and technology transfer and commercialization.

Still, in setting out the specific actions for VRIF, it is evident that fully addressing the strategic needs goes beyond its current and proposed funding levels. The $8 million recently proposed by Governor McAuliffe in the 2018–2019 biennial budget is significant in terms of Virginia's overall investment in innovation programs; however, even adding together the other ongoing innovation efforts in Virginia, the level of funding available is significantly less than in other leading innovation states, such as Massachusetts, Maryland, Pennsylvania, Colorado, and Texas.

To more fully meet the challenges facing Virginia, an enhanced set of actions are also set out as part of the strategic directions for this research asset assessment study for the Commonwealth to consider. These enhanced actions far outstrip the resources available to the Virginia Research Investment Committee (VRIC) by creating the organizational capacity to take on a greater scale of activities and involve broader public-private partnership efforts.

Table ES-1 provides a summary of the recommended action plan to address the strategic priorities set out, including baseline actions for VRIC to consider and enhanced actions for the Commonwealth's leadership and key stakeholders to consider.

Table ES-1. Recommended Action Plan: Baseline Actions for VRIC to Consider and Enhanced Actions for the Commonwealth to Consider

Strategy One: Pursue the strategic growth opportunities through public-private collaborations in advancing translational research capacities

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 1: Establish a competitive translational research project fund involving industry and university partners in strategic growth opportunities	**Enhanced Action 1:** Support the formation and sustainment of industry-led statewide translational research centers in each of the strategic growth opportunity areas
Baseline Action 2: Raise Virginia's competitiveness to pursue major federal research center awards to multi-university, multi-industry collaborations through planning, program coordination, and outreach grants and offering matching state funds for facility and equipment costs	

Strategy Two: Strengthen University Technology Transfer and Commercialization Capacity

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 3: Seek legislation that clarifies state policy on goals of university technology transfer and commercialization and set out clear metrics for measuring value creation	**Enhanced Action 2:** Create a dedicated statewide Virginia research commercialization and new ventures development organization to advance promising university and federal lab technologies
Baseline Action 4: Advance a new multi-university and federal lab consortium with industry mentors to target proof-of-concept funding in the strategic growth opportunity areas, learning from the Virginia Innovation Partnership pilot	
Baseline Action 5: Provide programmatic funding to advance collaborative university approaches in technology transfer and commercialization	

Strategy Three: Bridge the disconnect between university research and Virginia-based company innovation

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 6: Support an industry R&D portal across Virginia research universities in strategic growth opportunity areas to tap university shared-use laboratories and expertise	**Enhanced Action 3:** Broaden the dedicated university technology commercialization and new ventures development organization to create a more robust and proactive industry partnerships component
Baseline Action 7: Establish a statewide competitive matching grant program for applied industry-university research projects for small- to mid-sized companies with projects in strategic growth opportunity areas	
Baseline Action 8: Support regional showcases of university innovations in strategic growth opportunity areas	

Strategy Four: Shore up Virginia's regionally based innovation capacities to generate more start-ups and advance high-growth companies

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline funding resources not able to address this strategic need separately from support for statewide development	**Enhanced Action 4:** Create a network of Virginia Regional Innovation Partnerships

The annual level of activities generated from the baseline actions informed by best practice examples is expected to be significant, including the following:

- Increased industry-university translational and applied research collaborations in the strategic growth opportunity areas, including as follows:
  - 30 to 45 individual Virginia company applied research projects with one or more universities
  - 15 collaborative translational research projects, each involving one or more universities with multiple companies
  - Facilitation of industry engagement and high-touch customer-oriented services through a network of university site miners to work with companies

- Improved university capacity to commercialize their research discoveries, including as follows:
  - 20 proof-of-concept projects with strong industry mentorship leading to 5 to 6 new start-ups annually
  - Streamlined university technology transfer and commercialization practices that place an emphasis on value creation through new start-ups and licensing to Virginia companies
  - Increased capacity through collaborative efforts across universities to share access to market and technical experts and entrepreneurial training.

Beyond the activities generated from putting VRIF's resources to work, several key outcome-oriented measures are suggested to track the direct contributions of the baseline actions, including the following:

- Industry R&D levels generated
- Licensing of university technologies to Virginia companies
- Milestones reached in licensing of university technologies to Virginia companies
- Number of new start-ups
- Follow-on funding to new start-ups
- Evidence of rising valuations in new start-ups
- New sales growth by existing and start-up companies assisted
- Industry rating on quality of services provided.

A. Introduction

This report sets out the first Commonwealth Research and Technology Strategic Roadmap to provide a cohesive and comprehensive investment framework for the Virginia Research Investment Fund and an independent, expert-led assessment to inform broader state efforts in innovation-led development.

The economic stakes around innovation-led development are high. It has long been understood that innovation is a key driver of economic growth, high-quality jobs, and rising standards of living—explaining not only the differences in economic growth among nations, but also at the level of state and regional economies. Economists at the Federal Reserve Bank of Cleveland found that increased innovation, evidenced by growing levels of patent activities, stood out as one of the significant factors for explaining a state's levels of per-capita income and educational attainment. Innovation and talent, which are highly linked, outpaced other factors such as tax burdens, public infrastructure, the size of private financial markets, rates of business failure, and industry structure.[3] This supports earlier studies that have found that two-thirds of the growth differential across metropolitan areas are based on the relative growth in high-technology industries and their concentration in local economies.[4]

As the 21st century unfolds, the performance bar for innovation-led development is rising. 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 to compete for innovation-led development. The U.S. Council on Competitiveness in its report, Innovate America, put the issue succinctly: "We believe that the bar for innovation is rising. And, simply running in place will not be enough to sustain America's leadership in the 21st century. … Today, the forces of global economic integration and advances in technology are creating a different and more complex challenge."[5]

Today's highly competitive, innovation-driven global economy means a state can no longer take for granted that it will succeed in innovation-led development simply because it possesses significant research assets across its public and private universities, federal research facilities, and advanced industries and a strong past standing in advanced industries.

3 Paul W. Bauer, Mark E. Schweitzer, and Scott A. Shane, "Knowledge Matters: The Long-Run Determinants of State Income Growth," Journal of Regional Science, 52(2), May 2012, pages 240–255.
4 Ross DeVol and Perry Wong, America's High-Tech Economy: Growth, Development and Risks for Metropolitan Areas, Milken Institute, July 13, 1999, page 5.
5 Council on Competitiveness, Innovate America: National Innovation Initiative Summit and Report, May 2005, pages 37–38.

Virginia Responds to the Rising Bar of Innovation: Creation of the Virginia Research Investment Fund

In response to this growing challenge for innovation-led development, the General Assembly and Governor McAuliffe acted in 2016 to put in place a new resource for innovation-led development across the Commonwealth, the Virginia Research Investment Fund (the "Fund" or VRIF). The primary mandate of the Fund is to focus on innovative and collaborative research, development, and commercialization projects and programs with a high potential for economic development and job creation opportunities.

Broad Objectives of The Virginia Research Investment Fund

- Foster innovative and collaborative research, development, and commercialization efforts in the Commonwealth in projects and programs with a high potential for economic development and job creation opportunities
- Position the Commonwealth as a national leader in science-based and technology-based research, development, and commercialization
- Attract and effectively recruit and retain eminent researchers to enhance research superiority at public institutions of higher education
- Encourage cooperation and collaboration among public institutions of higher education, and with the private sector, in areas and with activities that foster economic development and job creation in the Commonwealth

To maximize the value of the Fund's investments, a Virginia Research Investment Committee (VRIC) was established in legislation to bring together public and private leaders with a strong connectivity to broader economic development and ongoing state innovation-led development efforts. This committee includes four members from the Virginia Growth and Opportunity Board and five leaders of state government agencies and legislative committees, including the Secretary of Technology, the Secretary of Finance, and the Staff Directors of the House Appropriations Committee and the Senate Finance Committee. The Director of the State Council of Higher Education for Virginia (SCHEV)—the Commonwealth's coordinating body for postsecondary education with extensive experience and a proven record of success in leading state-level strategic planning, policy development, and implementation involving higher education—is designated as the Chair of VRIC and the staff of SCHEV are assigned to assist VRIC in administering the Fund.[6]

As VRIC began its evaluation and awarding of investments, it soon recognized the need for a more strategic roadmap to help guide the investment of the Fund. Through legislative action in 2017, SCHEV was authorized to develop the Commonwealth Research and Technology Strategic Roadmap.

SCHEV retained TEConomy Partners, LLC (TEConomy) to assist with the analysis to bring an independent, expert assessment and knowledge of best practices to develop the Strategic Roadmap. TEConomy has a proven track record in conducting rigorous and robust assessment studies of research and development (R&D) assets and overall innovation ecosystems in states—including Arizona, Arkansas, Connecticut, Georgia, Indiana, Massachusetts, New Hampshire, Ohio, and Utah—that inform the targeting of innovation-led growth opportunities found in a state as well as strategic actions to further innovation-based development.

6 *For more details on the legislative authorization for VRIF and VRIC, see Code of Virginia Article 8, sections 23.1-3130–3134 at https://law.lis.virginia.gov/vacodefull/title23.1/chapter31/article8/.*

Approach to the Strategic Plan

The strategic roadmap planning effort involved a multiphase effort beginning in late August 2017 and culminating in its submission to VRIC in early January 2018. Throughout this process, there was close consultation with the staff of SCHEV and four interim meetings were held with VRIC to present interim results.

- In Phase I of the project, completed in early October, a comprehensive and integrated analysis of a wide variety of R&D data sources was completed using advanced analytical approaches. This analysis provided an in-depth and objective cataloging of Virginia's R&D competencies found across universities, federal labs, and industry. It began to identify where gaps and misalignments exist from a translational research perspective across these core R&D competencies.

- In Phase II of the project, completed in early December, the data analysis insights from Phase I were complemented with outreach to key leaders from university, federal labs, and industry to help in validating and refining the Phase I assessment of the gap analysis and core R&D competencies and in advancing the growth opportunities identified for Virginia. Plus, an assessment of program and policy issues relating to Virginia's state and university policies, practices, and regulations and state-funded innovation grant programs was undertaken to provide a context for recommended actions.

- In Phase III of the project, completed as part of this final report, recommendations were developed drawing upon the extensive best-practice knowledge of TEConomy. At each phase of the project, insights from best practices were discussed with VRIC.

Three stand-alone analyses were prepared as separate appendices informing this final report:

- An assessment of Virginia's standing across the complete life cycle of research, development, and commercialization—or what is commonly referred to as the innovation ecosystem.

- An identification of strategic growth opportunity areas with line-of-sight across industry innovation and research institutions in Virginia.

- A review of university technology transfer policies and practices for research universities in Virginia.

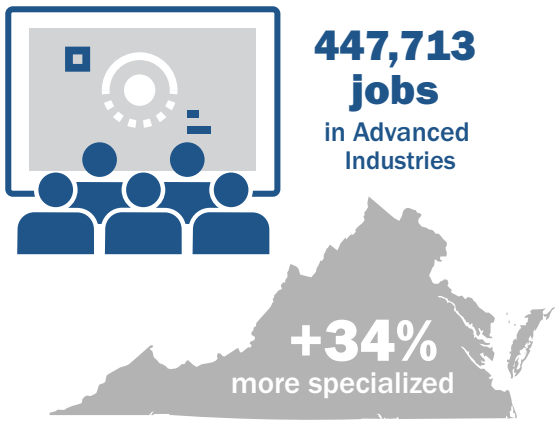
B. The Context: Virginia's Standing in Innovation-Led Development Offers Significant Strategic Growth Opportunities

Across many measures of innovation-led development, Virginia today stands as one of the nation's leading innovation states. A quick snapshot of the most recent annual data available suggests the depth and breadth of Virginia's activities across its innovation ecosystem involving the following:

- Concentration of jobs found in advanced industries
- Entrepreneurial energy
- Size of R&D base.

Virginia has a high concentration of jobs in advanced industries:

- ***With 447,713 jobs, Virginia is 34 percent more specialized in its concentration of advanced industries than the nation.*** For many, this is the ultimate measure of innovation development—creating jobs in industries innovating and deploying advanced technologies to compete. These advanced industries, including 50 specific industries that range across manufacturing industries to computer and information services to energy industries to bioscience industries to engineering and commercial research services, are characterized by the following:



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

According to the Brookings Institution, 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."[7]

- ***Of the 50 advanced industries, Virginia stands out in 13 with higher concentration of jobs than found across the nation.*** These reflect a broad mix of advanced manufacturing industries; information technology and telecommunications industries; a biosciences industry; and scientific, engineering, and technical services industries. Many of these leading advanced industries in Virginia employ more than 10,000 workers.

The leading 13 advanced industries found in Virginia based on having a higher concentration of employment are as follows:

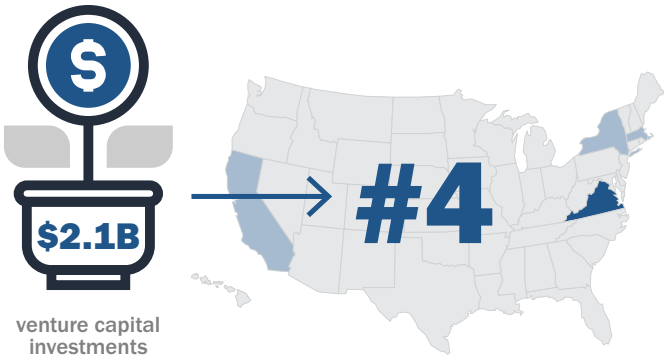
- **Computer systems design and related services**, with 158,122 jobs in 2016 and a 212 percent higher level of industry employment concentration in Virginia than the nation
- **Management and technical consulting services**, with 74,541 jobs in 2016 and a 115 percent higher level of concentration in Virginia than the nation
- **Engineering and architectural services**, with 53,558 jobs in 2016 and a 49 percent higher level of concentration in Virginia than the nation
- **Ship and boat building**, with 23,706 jobs in 2016 and a 591 percent higher level of concentration in Virginia than the nation
- **Scientific R&D services** with 23,006 jobs in 2016 and a 32 percent higher level of concentration in Virginia than the nation
- **Data processing, hosting and related services**, with 11,286 jobs in 2016 and a 47 percent higher level of concentration in Virginia than the nation
- **Medical and diagnostic laboratories**, with 7,888 jobs in 2016 and a 16 percent higher level of concentration in Virginia than the nation
- **Electrical equipment manufacturing**, with 5,874 jobs in 2016 and a 65 percent higher level of concentration in Virginia than the nation
- **Resin, rubber, and artificial fibers manufacturing**, with 4,841 jobs in 2016 and a 103 percent higher level of concentration in Virginia than the nation
- **Other chemical product and preparation manufacturing**, with 3,810 jobs in 2016 and a 83 percent higher level of concentration in Virginia than the nation
- **Other telecommunications**, with 3,758 jobs in 2016 and an 87 percent higher level of concentration in Virginia than the nation
- **Railroad rolling stock manufacturing**, with 1,019 jobs in 2016 and a 54 percent higher level of concentration in Virginia than the nation

7 Brookings Institution, America's Advanced Industries: What They Are, Where They Are, And Why They Matter, Brookings Advanced Industries Project, February 2015, page 11.

- **Satellite telecommunications**, with 308 jobs in 2016 and a 54 percent higher level of concentration in Virginia than the nation.

Virginia is a national leader in entrepreneurial energy, with strong levels of venture capital investment and fast-growth companies:

- With $2.1 billion in venture capital investments made in emerging companies in 2016, Virginia ranks fourth in the nation in venture capital investment per size of the state's economy. Only California, Massachusetts, and New York rank higher.[8] Venture capital investment is a hallmark of technology-based entrepreneurship in a state. 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.

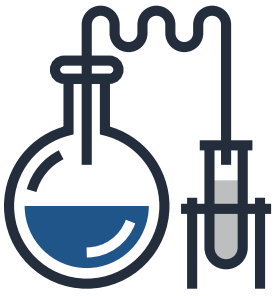


- With 270 Virginia-based companies recognized as fast-growth privately held companies on the Inc. Magazine 5000 listing for 2016, Virginia comprises 5.4 percent of all companies, well above the 2.7 percent share of the nation's economy that Virginia represents. The Information Technology Innovation Foundation (ITIF) ranks Virginia first in the nation in fast-growth companies over the past two years as a share of total companies in the state based on Census data.[9]

Virginia has a sizable base of research activities, led by federal labs and federal funding:

- With $10.5 billion in total research funding in 2015, Virginia ranks 13th in the nation in actual dollars, though slips to 21st after adjusting for the size of the economy.

- Virginia, with $4.6 billion of research funding in 2015 across its multitude of federal intramural labs and federally funded R&D centers, stands four times higher than the national level relative to the size of its economy. This base of federal labs is a key



$10.5B
in research funding

13th
in the nation in actual dollars

8 See Information Technology Innovation Foundation, 2017 State New Economy Index, for full rankings of venture capital per state gross domestic product, page 50.
9 Ibid., page 33.

driver of technology development in the state generating over 700 patent awards and applications from 2014 to mid-2017.

- 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 with just short of 8 percent nationally. Virginia also has a substantial base of federal Small Business Innovation Research (SBIR) 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.

The strength of Virginia in innovation-led development is noted in comprehensive scorecards on innovation produced by the Milken Institute and ITIF. ITIF ranks Virginia 4th in the nation in its *2017 State New Economy Index*, its highest ranking since the index was first released in 1999, when Virginia ranked 12th in the nation. The Milken Institute's 2016 State Technology and Science Index ranks Virginia 9th down from 7th in 2014. So, these are slightly different views that still place Virginia among the top 10 states in innovation-led development.

Given this extensive base of activity, it is not surprising that Virginia has significant strategic growth opportunities emerging from its innovation-led base of activity.

Identifying Strategic Growth Opportunities through a Line-of-Sight Analysis

While individual measures of innovation activity suggest the preparedness of a state for innovation-led development, they do not offer an understanding of the strategic growth opportunities in innovation that a state is best positioned to pursue successfully. In today's global economy where knowledge and innovation are the driving forces for economic growth, the opportunity set of technologies that R&D capabilities across universities, industries, and federal labs can help in advancing is enormous. In reality, each state has its own specific areas of excellence across its university, industry, and federal lab R&D activities through which it is best positioned to differentiate itself and build specialized areas of expertise where it can be a world leader in technology commercialization and innovation-led development, i.e., core R&D competencies.

It is a lesson that industry has learned well by focusing on its core competencies to advance competitive advantage that leads to growth in the global marketplace. As Gary Hamel and C.K. Prahalad in their landmark study, *Competing for the Future*, explain: "To successfully compete for the future … requires top management to conceive of the company as a portfolio of core competencies rather than a portfolio of individual business units. … core competencies are the gateways to future opportunities."[10]

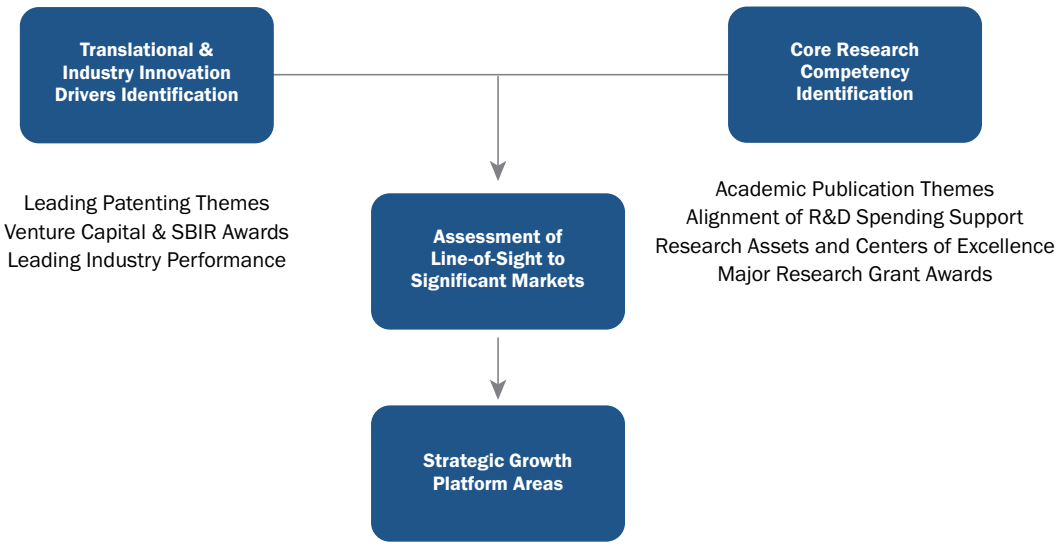
Core competencies can be thought of as a "bundle of skills and technologies" that enables innovation and growth. From a state and regional technology-based economic development perspective, core R&D competencies represent where a state has the "know-how" across its industries and research institutions, involving universities, federal labs,

10 Gary Hamel and C.K. Prahalad, Competing for the Future, Harvard Business Press, 1994, pages 90 and 217.

and nonprofit organizations, to position the state for future growth in targeted markets. This includes focused areas where industry and research institutions in the state can bring a critical mass of activity along with an identified measure of excellence and alignment across key industry, university, and federal labs.

With an understanding of a state's core competencies across research institutions and industry, it is possible to then examine the extent to which they are robust, strategic growth opportunities with capabilities supported by both research institutional and industry core competencies where Virginia is best positioned to differentiate itself. Strategic growth opportunities representing highly aligned competency areas across industry and research institutions reflect the intersection, or "line-of-sight," where the state has the know-how and capacity to grow in the future. Figure 1 presents the overall approach and the specific metrics used in this assessment to identify a "line-of-sight" to strategic platforms that consider the market pull of leading advanced industries found in Virginia and the technology push from the state's university research capabilities.

Figure 1. Line-of-Sight Approach for Identifying Strategic Growth Platforms for Virginia



Areas where Virginia **has real, differentiating potential**

The first step in the line-of-sight approach is to assess the core R&D competencies that are found in the output of research and technology development activities undertaken by research institutions and industry. This involves an in-depth analysis of documented activities in the following:

- Peer-reviewed research publications that largely represent the scholarly activities of research institutions in Virginia, with the 53,000 publications generated from 2014 to mid-2017.

- Patent/intellectual property (IP) activities that largely reflect the focus of industry R&D, with 20,663 patent awards and applications being filed by inventors residing in Virginia from 2014 to mid-2017.

This type of quantitative analysis enables the use of sophisticated machine learning algorithms to assess the tens of thousands of records found in publications and technology classification areas listed in patents to identify how these activities relate to each other.

The aim of the core competency analysis is to set the broad context or themes of where research and technology development activities in Virginia across research institutions and industry have a critical mass. These analyses found 35 cluster groupings of core competency areas in scholarly activities from publications and 9 areas of leading patent innovation network groupings that together help to offer insights into innovation themes found across Virginia's R&D base.

These publication clusters and patent innovation networks were then reviewed closely to learn how well they aligned together into potential innovation platforms bridging the areas of focus found in Virginia's research institutions and industry innovation.

The second step of the analysis was to consider the depth, excellence, and alignment of these potential innovation platforms based on a broader set of measures of research excellence and innovation activities taking place in Virginia.

For the research institution innovation capacity, the key measures include the following:

- Presence in publications cluster analysis, which offers a measure of the intensity of the specific research innovation themes supporting key platform areas

- Strength of leading publication fields (>100 overall publications in field across Virginia) aligned with platform area, which offers an indexed measure of the combination of the volume of publishing as well as the specialization of Virginia's activity relative to national trends

- Presence of university and lab R&D spending in discipline areas aligned with platform area, which offers an indexed measure of the combination of the total dollars spent as well as the intensity of Virginia university spending relative to national trends

- Presence of major grant awards including those over $1 million and competitively funded research centers, including those with industry

- Presence of leading research centers with shared-use infrastructure.

For industry innovation capacity, the key measures include the following:

- Presence in patent innovation networks, which offers a measure of the intensity of the specific applied innovation themes supporting key platform areas

- Strength of leading patent technology class areas (>20 overall patents in class) aligned with platform area, which offers a measure of the combination of the volume of patenting activity as well as the specialization of Virginia's activity relative to national trends

- Presence of venture capital funding aligned with platform applications areas, which offers a measure of the combination of the total equity invested in specific, detailed technology areas as well as the intensity of Virginia's investment levels relative to national trends

- Presence of Phase 2 SBIR awards aligned with platform applications areas, which gives a measure of the level of emerging industry innovation associated with platforms

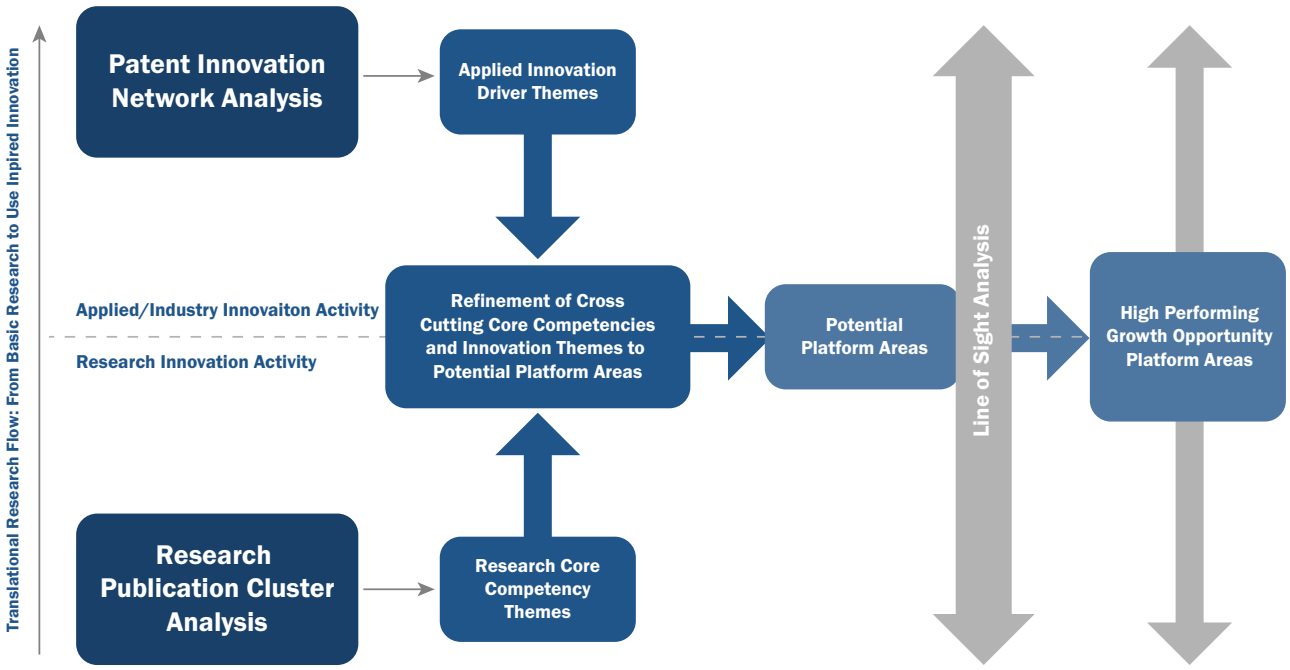
- Presence of large bases of employment in aligned, detailed, six-digit North American Industry Classification System (NAICS) advanced industries, which offers insights into specific product markets served, that are available to support capacity in innovative industry development (indexed based on relative distribution of Virginia NAICS code employment levels)

- Presence of specialized six-digit NAICS advanced industries aligned to a platform area that can provide competitive advantages relative to other regions to support innovation activity (indexed based on location quotient of Virginia NAICS industry employment relative to the United States).

These metrics were used to create average total "scores" for research and industry innovation factors that evaluate the line-of-sight to market for each innovation-led platform across the spectrum of translational research and commercialization activity. Platform areas can then be assessed based on the strength of alignment that they have across both research innovation and industry innovation drivers to determine priority platform areas that can drive technology-based economic development for Virginia.

Figure 2 lays out this process of utilizing core competency analyses to identify potential platform areas for evaluation using the line-of-sight perspective.

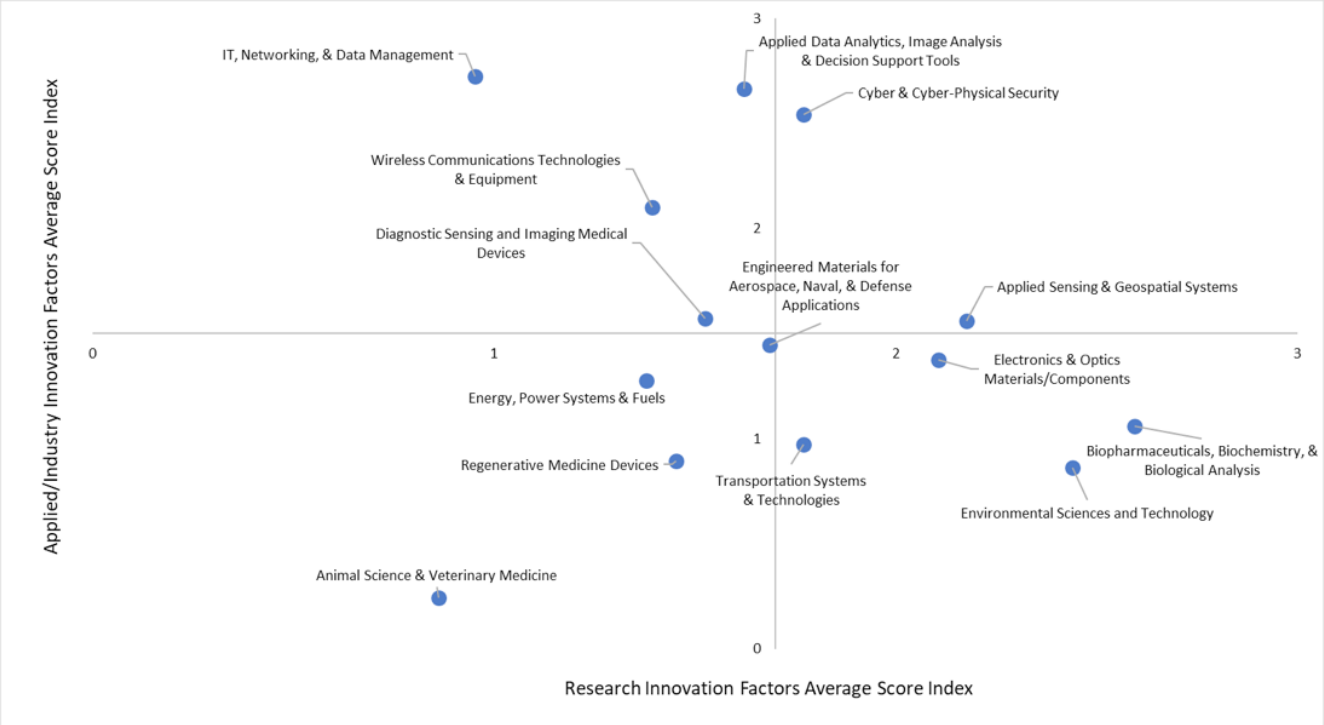
Figure 2. Using Core Competency Analyses to Identify and Evaluate Virginia's Potential Growth Platforms Using Line-of-Sight Analysis



A combined examination of the patent innovation networks and research publications clusters analyses revealed 14 potential platforms based on innovation strength themes in Virginia that might serve as strategic growth opportunities. The line-of-sight analysis further demonstrates the areas of relative strength in each platform within Virginia and highlight those potential innovation platform areas which are aligned across the research-industry innovation pipeline to best provide growth opportunities.

The combination of research and industry innovation factors reveals that, with the exception of cybersecurity and cyber-physical security, there are no potential innovation platform areas that display overwhelming strength across both research and applied/industry innovation factors to serve as a strategic growth opportunity. However, many platforms have either strong research alignment or industry alignment with moderate or below-average alignment across the other dimension (Figure 3).

Figure 3. Assessment of Virginia's Potential Innovation Platform Areas across University Factors and Industry Factors



While no individual innovation platform rises in the line-of-sight as having the strength in research factors and industry innovation factors to serve as a strategic growth opportunity area, with the notable exception of cybersecurity and cyber-physical security, it is possible to bring together multiple innovation platforms representing cross-cutting, multidisciplinary capacities that set out distinct areas where Virginia has the ability to leverage its collective research and industry innovation assets to drive economic growth and to focus resources and aggregate innovation activity into meaningful initiatives.

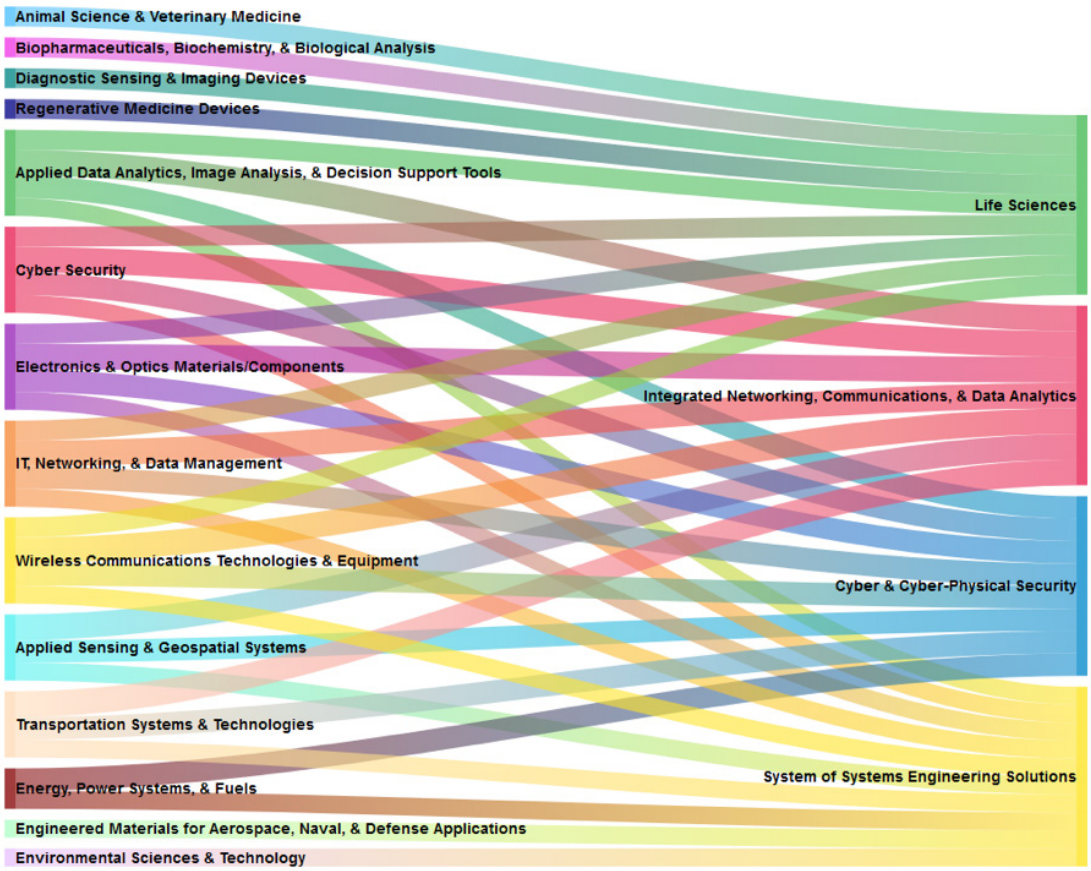
Consulting with industry leaders and regional technology councils and further deliberating on the mix of potential innovation platforms and their market potentials led to the identification of four strategic growth opportunities that best align research and industry innovation strengths with growing market opportunities for Virginia:

- **Cyber and Cyber-Physical Security**
- **Integrated Networking, Communications, and Data Analytics**
- **System of Systems (SoSE) Engineering Solutions**
- **Life Sciences.**

Each of these strategic growth opportunities are able to drive growth across a broad base of industries and serve as a focusing mechanism for translational research from multiple disciplines to give Virginia the ability to compete in the modern technology-based innovation economy.

Figure 4 shows the comprehensive way in which the strategic growth opportunities incorporate multiple innovation platforms within the scope of their applications and market opportunities. Detailed profiles and recommended development pathways for each growth opportunity are laid out in the sections below.

Figure 4. Cross-Cutting Relationships between Virginia Innovation Platforms and Virginia Strategic Growth Opportunity Areas



Below is a brief description of each strategic growth opportunity with an indication of the growth markets it can serve and innovation activities taking place in Virginia. More detailed profiles for each of the four strategic growth opportunities is provided in Appendix A to provide a fuller explanation of the opportunity, the industry context found in Virginia, the research and innovation context and the leading market applications and growth potential and, finally, the development challenges and potential development pathways to be considered.

Cyber and Cyber-Physical Security: Cybersecurity involves protection of computer hardware, software, and data from threats ranging from theft to destruction. This rapidly evolving area involves the creation and maintenance of technologies designed to counter threats both proactively and in real time in addition to assessing damage and conducting repairs in the wake of attacks. Many major industries have experienced cybersecurity attacks in recent years, and given the fundamental importance of databases and networking to modern business processes, innovative cybersecurity technologies will continue to be a key area of active R&D for the foreseeable future. In addition to

traditional computer systems, an increasing variety of connected smart devices and infrastructure must also be protected from analogous attacks designed to exploit the architecture of the "Internet of Things" (IoT). As vulnerability becomes an increasing concern for consumer devices connected to the Internet, security will also become an issue for the physical infrastructure and hardware systems that manage public utilities, transportation, medical care, military systems, and industrial automation.

Virginia is already highly regarded as a top state in cybersecurity, with the highest concentration of cybersecurity workforce in the nation and standing only second to California in total cybersecurity jobs. In recent years, Virginia has made recent strides toward positioning its research institutions as world-class research assets dedicated to modern cybersecurity and cyber defense applications. The state government, led principally by the Virginia Cyber Commission and the initiatives developed from its recommendations around education and workforce development, has invested considerable effort over the past several years in raising the profile of Virginia as a destination for cybersecurity talent and innovative research. Additionally, increasing demand from U.S. Department of Defense clients for new cyber defense products and services has helped ground significant industry presence in the northern Virginia region. The presence of major federal labs involving cybersecurity also stands out, particularly having MITRE leading the National Security Engineering Center, with over $900 million in annual funding.

This focus on branding Virginia as a cybersecurity hub has translated to several key centers of excellence among Virginia's public universities. Virginia Tech was designated a National Center of Academic Excellence in Cyber Defense Research in May 2017, making it one of only 16 universities in the nation to achieve the designation. Its innovation assets in this area are spearheaded by the Hume Center for National Security and Technology and supported by five other major labs and centers in cybersecurity applications, with key strengths in cyber-physical security. Additionally, at the University of Virginia (UVA) the Link Lab was created in 2016 via the UVA Strategic Investment Fund to build out a collaborative initiative in cyber-physical systems technology, and George Mason University was designated as a National Center of Academic Excellence in Information Assurance/Cyber Defense Research and Education based on its multidisciplinary programs focused on secure information systems.

Integrated Networking, Communications, and Data Analytics: Advancements in the state of connectivity and the ability to process massive volumes of unstructured data have resulted in the need for solutions to address the connectivity and processing power behind modern communications technologies. Today's telecommunications networks rely on a mix of wired and wireless voice and data communications networks, broadband internet networks, and data storage infrastructure that require complex routing and retrieval processes with an ever-increasing user base. Next-generation networks will combine all these communications assets with more traditional data-processing technologies to create an integrated system that businesses and governments can leverage to provide connectivity and analytical services.

Integrated communications and data networks will provide cutting-edge technology solutions that improve multiple aspects of the communications pipeline, including the following:

- Point-of-access connectivity and speed, particularly wireless technologies designed for secure communications and networking of smart devices and unmanned systems (including defense and "ad hoc" network applications)
- Efficient routing of high volumes of data-driven communications traffic utilizing an interconnected mix of legacy wired, next-generation high-speed wired, and wireless network node assets optimized at a system-wide level
- Rapid retrieval and processing of "big data" from data storage centers supported by highly automated and secure data center facilities
- Rapid processing of large databases to drive endpoint analytics applications such as machine learning models using on-demand virtual processing resources
- Resilient, distributed infrastructure to support cloud-based services and software in a global market.

Virginia has a significant user base of these technologies, particularly in financial technologies (fintech) and government services, as well as a geographical specialization—northern Virginia has one of the largest clusters of data centers in the nation, and some estimates indicate that up to 70 percent of the world's internet traffic passes through the region.[11] Additionally, the area has robust innovation activity across various wireless networking technologies and computer services to support ongoing development of innovation targeted toward building next-generation integrated communications frameworks. Virginia is also well positioned to become even more integrated as a global node in networking and communications due to operation of the MAREA transoceanic cable station, the first in the mid-Atlantic region.

Concurrently with the push for greater leverage of data storage and transmission capabilities, there is an accelerating demand for data analytics applications that can leverage the increasingly enabled flows of "big data" from the state's infrastructure. The state has recognized the importance of this area through its DataVA effort and through the growth of a number of data sciences–centric institutes and centers at Virginia Tech, UVA, George Mason University, and others. However, the state's focus and branding in analytics required to build out a specialized identity in today's competitive market is still emerging, with much of the critical mass in data analytics still reliant on large anchor industry operations specializing in broad services rather than centers of excellence within universities. Pockets of excellence within the university system in data analytics have not yet fully integrated their role with networking and communications innovation assets and must continue to build out more specialized identity in key applications to succeed over the long term.

System of Systems Engineering Solutions: System of systems engineering (SoSE) is an emerging discipline that combines interdisciplinary engineering and scientific disciplines to design, assemble, and manage complex systems made up of a number of finite components, each of which themselves may constitute a system.[12] As an example, a modern naval vessel will have many different subsystems ranging from propulsion to navigation that are all interconnected through electrical and communications networks and require effective operation by a crew to ensure safety and efficiency. As opposed to traditional systems engineering, which itself is a key supporting discipline for SoSE, the system of systems approach is concerned with an overall system defined by the interactions of various

11 *Virginia Economic Development Partnership—Data Centers: Industry Overview. http://www.yesvirginia.org/KeyIndustries/DataCenters.*

12 *M. Jamshidi, "System-of-Systems Engineering—A Definition," Proceedings of the IEEE SMC 2005 International Conference on Systems, Man and Cybernetics, October 10–12, 2005.*

subsystems supporting an overall technology platform rather than focusing on engineering individual components. Because it is principally concerned with integration of many component subsystems, SoSE typically relies on solving networking and interoperability challenges that involve technology areas such as sensors, power electronics, communications, advanced materials, and command and control interfaces.

Although SoSE technologies and approaches have traditionally been oriented toward aerospace and defense applications, innovative applications have increasingly been oriented toward automation and unmanned systems in "civilian" areas such as manufacturing, communications and data infrastructure, power grid operations, healthcare delivery, and transportation. Technology areas that are key enablers of the integrated life cycle approach used in SoSE applications include digital design, simulation and modeling, advanced sensing and instrumentation, and distributed computing.

Virginia has a strong history of engineering excellence grounded by federal and research university assets. The state is home to world-class engineering research assets such as the National Aeronautics and Space Administration (NASA) Langley Research Center; the Mid-Atlantic Regional Spaceport (NASA Wallops Flight Facility); Dahlgren Naval Surface Warfare Center; Newport News Shipbuilding; the Commonwealth Center for Advanced Manufacturing (CCAM); and many other federal intramural labs, federally funded R&D centers, consortia, and private organizations engaged in R&D activities in key engineering applications. The university system plays a complementary role in enabling this focus on innovative solutions with key engineering-related testing and research centers linked to high-profile engineering departments at Virginia Tech, UVA, George Mason University, and Old Dominion University (ODU). Many signature facilities help enable the strong focus on applied engineering, including Virginia Tech and the Mid-Atlantic Aviation Partnership's Federal Aviation Administration (FAA)-designated unmanned aircraft systems (UAS) testing site and the Virginia Tech Transportation Institute; ODU's Virginia Modeling, Analysis, and Simulation Center; and UVA's Applied Research Institute and partnership role with CCAM, just to name a few.

Life Sciences: Life sciences development in Virginia is still very much being defined through the commercialization of university research and the collaborations unfolding between academic medical centers and Virginia's major hospital systems. This footprint is one of the most geographically diverse in Virginia given the location of the state's academic medical centers and hospital systems. Communities across Virginia, such as Richmond, Roanoke, Norfolk, and northern Virginia, are actively engaged in life sciences development, providing a true state-regional connective tissue for development. The upside for Virginia is significant, but life sciences development is a marathon given the long-time horizons for new product development and one that must have sustained investment to succeed.

Growth opportunities in this space fall into a broad spectrum of interdisciplinary technologies focused around biology, biotechnology, and medicine. An advanced innovation ecosystem supporting these areas takes promising innovations developed from basic research in biological science and then quickly translates them into medical or other biotech product and service applications. Integrated bench-to-market processes will increasingly play a key role in advancing new market technologies in life sciences and rely on a well-functioning clinical research environment centered around academic medical centers to enable drug development and clinical trials as well as a well-supported entrepreneurial environment for emerging biotechnology companies.

Endpoint markets for innovations in advanced life sciences can include the following:

- Biopharmaceuticals tailored to specific genetic and metabolic biomarkers for treatment of disease
- Advanced diagnostic and testing technologies enabled by genetic sequencing, high-throughput sample processing, advanced medical imaging, and novel testing materials development
- Medical devices, particularly those used in diagnostic sensing for clinical care and regenerative medicine focused on biocompatible and implantable materials
- Bioinformatics involving the integration of big data processing and predictive modeling for use in computational biology and healthcare applications
- Commercial and industrial biotechnologies for use in industrial, agricultural, and other bioprocess engineering applications.

Virginia's diversity of biomedical and biotechnology innovation assets and the emerging nature of the state's industry ecosystem in this area mean that it is important to keep a broader perspective in supporting innovative advancements over time as more distinct areas of specialization develop and mature. Several key areas of innovation developing today revolve around the use of integrated diagnostic and drug development technologies to advance personalized medicine, regenerative medical devices, neurosciences, and life science manufacturing.

Together, these four strategic growth opportunities are able to engage each of the major advanced industries in which Virginia stands out, offering an opportunity for broad-based economic development efforts around innovation to drive new start-ups, retain and grow existing businesses, and attract outside companies (Table 1).

Table 1. Mapping of Strategic Growth Opportunities and Leading Advanced Industries in Virginia

Strategic Growth Opportunity	Alignment with Leading Advanced Industries in Virginia
Cybers and Cyber-Physical Security	Computer Systems Design and Related Services Management and Technical Consulting Services Engineering Services
Integrated Networking, Communications, and Data Analytics	Telecommunications Satellite Telecommunications Data Processing, Hosting, and Related Services Computer Systems Design and Related Services Management and Technical Consulting Services Engineering Services
System of Systems Engineering	Engineering Services Ship and Boat Building Electrical Equipment Resin, Rubber, and Artificial Fibers Other Chemical Products Railroad Rolling Stock Management and Technical Consulting Services Scientific R&D Services
Life Sciences	Medical and Diagnostic Laboratories Scientific R&D Services

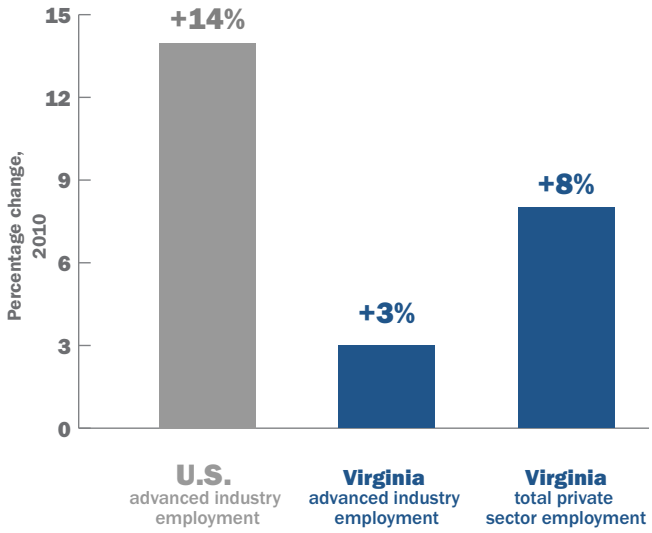
C. The Challenges: Headwinds Holding Back Virginia's Growth in Innovation-Led Development

Despite having a sizable base of innovation activity and strategic growth opportunities, Virginia's innovation ecosystem is underperforming. Since the economic recovery began in 2010, there has been a significant divergence between the overall innovation capacity found in Virginia and the trends and dynamics in innovation.

The signs of lagging performance in Virginia's innovation ecosystem are unmistakable:

Advanced industry growth is lagging the nation: While the nation grew by 14 percent in advanced industry employment, Virginia grew a modest 3 percent, which was even well behind the state's growth in total private sector employment of 8 percent (Figure 5).

Figure 5. Employment Growth Comparisons, U.S. Advanced Industries, Virginia Advanced Industries, and Virginia Total Private Sector Industries, 2010–2016



Source: TEConomy Partners' analysis of U.S. Bureau of Labor Statistics, Quarterly Census of Employment and Wages data; enhanced file from IMPLAN Group.

This lagging growth is not centered in one or two advanced industries, but is prevalent across most of the leading advanced industries found in Virginia. The 13 leading advanced industries break down as follows:

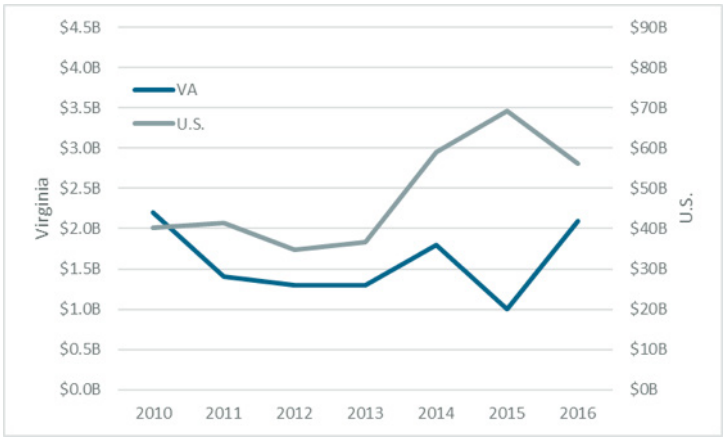
- Only two gained jobs at a rate faster than the nation from 2010–2016—railroad rolling stock manufacturing and other chemical product and preparation manufacturing.

- Four gained jobs from 2010–2016, but at a level below the United States—medical and diagnostic laboratories, computer systems design and related services, management and technical consulting services, and data processing/hosting.

- Seven 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 R&D services.

From 2010 to 2016, venture capital has flattened out in Virginia, while rising nationally: Virginia has been consistently well below the $2 billion mark, which it hit in 2010 and 2016, while the nation stands well above its 2010 level in recent years (Figure 6).

Figure 6. Trends in Venture Capital Investment, Virginia and the United States, 2010–2016



Source: TEConomy Partners' analysis of Thomson ONE database.

Virginia declined in overall research funding from 2010 to 2015, while the nation grew: In overall research funding, across industry, federal labs and university fell by 6.3 percent or nearly $500 million from 2010 to 2015, while nationally total R&D activity rose a healthy 14.5 percent.

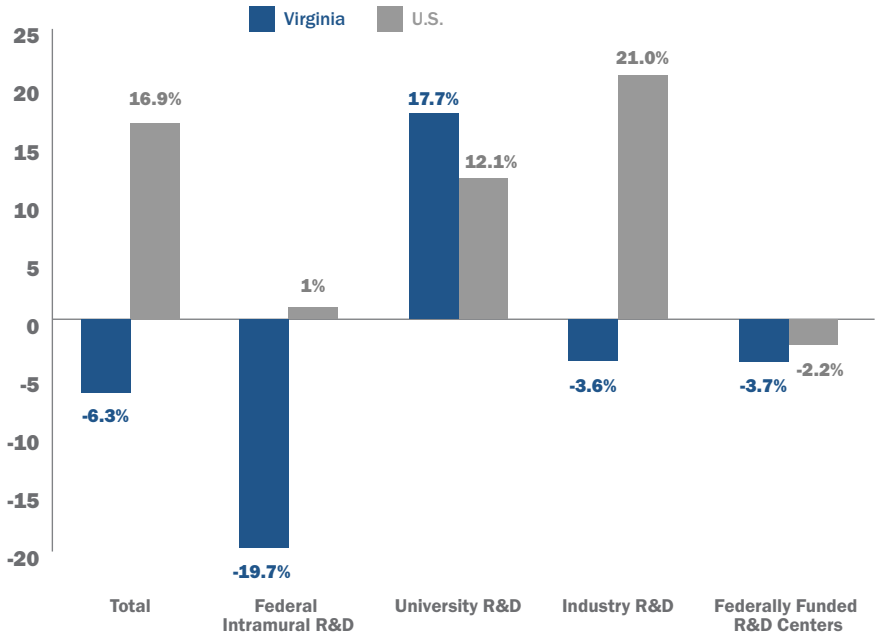
Virginia was one of only 12 states and the District of Columbia that recorded declines in overall research funding. The other states recording declines in overall research funding, though, were generally small research states, with the notable exceptions of Minnesota and Missouri.

Other leading states in overall research funding recorded strong growth, including California (+54 percent), Massachusetts (+42 percent), Michigan (+29 percent), Texas (+57 percent) and Maryland (+33 percent)—meaning Virginia is losing ground to top states.

Looking across the sectors of research activity, the largest decline for Virginia was found in its federal intramural labs (-20 percent) and federally funded R&D centers (-3.7 percent). But, industry R&D in Virginia also declined a significant 3.6 percent, while growing robustly nationally, due to its dependence on federal research funding contracts (Figure 7).

So, without a doubt, Virginia's slowdown in innovation activity, impacting not just research but advanced industry employment, can be traced to declining levels of federal research support in the state.

Figure 7. Percentage Change in Research Funding by Sectors, Virginia and the United States, 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.

Still, closer review reveals underlying challenges facing Virginia's innovation ecosystem that need to be addressed to unleash Virginia's potential for innovation-led development. The concern is that, even if federal research activity picks up, Virginia will still underperform in its potential growth from translating its research assets into tangible economic growth.

These underlying challenges include the following:

- Addressing the low levels and lagging growth of industry R&D from own-company sources that focus on developing new products and services.

- Strengthening university capacities in technology transfer, commercialization, and industry partnerships.
- Bridging the disconnect between existing Virginia industry and university research activities that is deeply rooted.
- Shoring up entrepreneurial development efforts across regions in the Commonwealth.

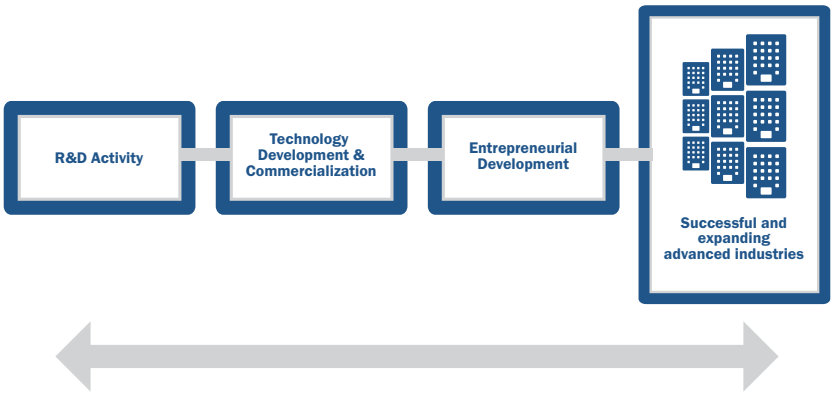
Each of these challenges is described in detail below. These challenges range in their scale and scope, but reinforce each other and together significantly hold back the ability of Virginia to have a high-functioning innovation ecosystem capable of realizing the potential of its strategic growth opportunities.

For innovation-led development to be realized, it is not only the size of research assets that matters, but also the ability to translate those research assets into new products, processes, and start-up ventures that drives advanced industry growth and high-quality job creation. As the National Research Council explains, "Innovation encompasses not only research and the creation of new ideas, but the development and effective implementation of the technology into competitive products and services."[13]

A high-functioning innovation ecosystem generates economic growth through an interconnected value chain of public and private economic development resources and services across the stages of R&D activities, technology development and commercialization activities, entrepreneurial development activities, and ultimately growing employment in advanced industries. But, the process of innovation is not simply a pipeline, but a more complex, bidirectional feedback loop in which market needs and requirements inform and shape the process in which research moves forward and succeeds in generating economic value. Therefore, the connections taking place across industries, universities, and federal labs in their research and technology commercialization is an important dynamic to consider.

If any link in the chain as depicted in Figure 8 is weak or not well connected, then a state will not realize its full potential in innovation-led development.

Figure 8: Linkages in an Innovation Ecosystem Leading to Economic Development



13 Charles W. Wessner and Alan Wm. Wolff, Editors, *Rising to the Challenge: U.S. Innovation Policy for the Global Economy*, National Research Council, National Academies Press, 2012, page xiii.

Challenge: Addressing the low levels and lagging growth of industry R&D from own-company sources that focus on developing new products and services.

Overall, the level of industry R&D activity in Virginia is less than half that of the nation relative to the size of its economy. Virginia has $1.1 million of industry R&D activity per $1 billion of gross domestic product (GDP), compared with $2.4 million nationally.

This is a very surprising result. One would have suspected that, given the fact that Virginia is 34 percent more concentrated in its private-sector employment in advanced industries, it would surely have a stronger base of industry R&D. In fact, industry R&D per advanced industry job in 2015 stood at $10,126 for Virginia, compared with $27,682 for the nation.

The reason for Virginia's weak level of industry R&D is its significantly lower level of own-funding by companies for R&D. Virginia is just a third of the U.S. level relative to the size of Virginia's economy in the amount its companies directly fund from their own revenues for research. Virginia has $652,000 of own-source company funding per $1 billion of GDP, compared with $2,028,000 nationally.

Virginia's higher federal funding of industry R&D cannot make up for this significant difference given the order of magnitude at which industry R&D activity is funded by companies. Nationally, the federal government funded $27 billion of a total of $356 billion industry R&D in 2015. While Virginia does well in federal research funding to industry, it simply pales in comparison with what drives overall industry R&D.

Plus, the nature of federal R&D is unlike company R&D funding. Federal research funding pays for contract research services to assist federal agencies in their missions, and so does not directly drive new commercial products. Company R&D funding from their own revenues pays for advancing new products and processes that go on to generate new revenues and more competitive companies that then drive job growth.

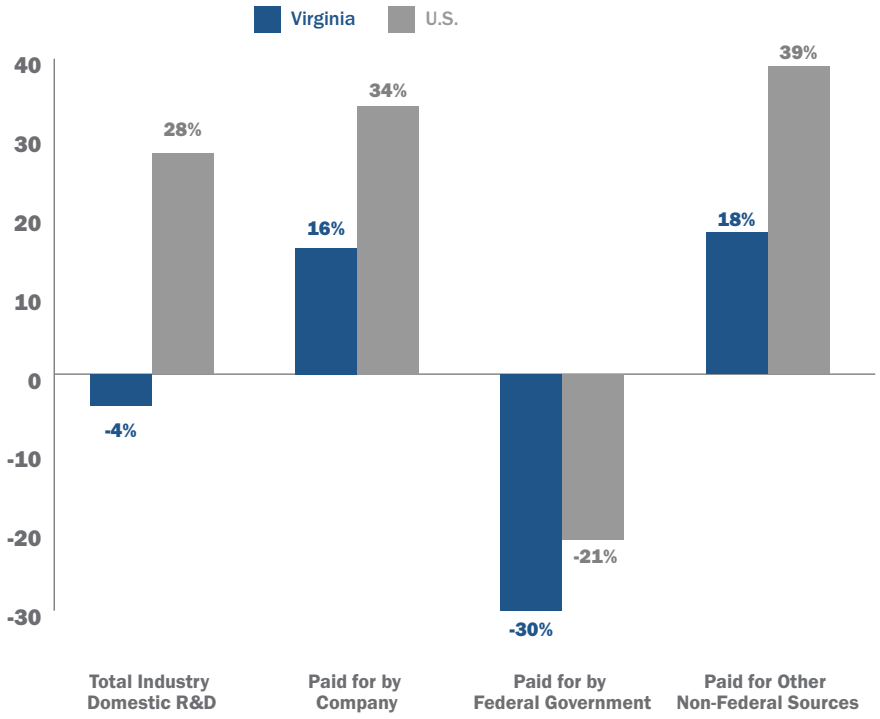
Consistent with this concern about lower levels of R&D paid for by companies from their own sources found in the state is that Virginia is also well behind the nation in the generation of new IP. In 2016, Virginia generated 6.8 patents per billion dollars of GDP, compared with 9.1 patents for the nation. Although there are other forms of IP protection through copyrights, trademarks, and trade secrets, patents are among the most widely used form of protection of novel R&D-led inventions and a good indicator of a state's ability to convert research to commercially relevant innovations.

While there is a significant number of new patents issued each year to inventors in Virginia, reaching 3,354 patents in 2016, it is hard to drive innovation-led development at the scale of the state's economy when it stands 25 percent below the level of the nation.

Recent growth trends are also not promising, showing Virginia falling further off the pace of the nation in industry R&D. Since the economic recovery began in 2010, Virginia's industry R&D activity has declined by 4 percent, while

increasing at a substantial 28 percent nationally (Figure 9). This difference reflects not only Virginia's greater reliance on a declining level of federal funding for industry R&D, but also a significant gap in the growth of own-source funding by companies for R&D. While federal funding for industry research in Virginia fell by 30 percent, it also declined by 21 percent nationally—a difference of 9 percentage points. In R&D paid for by companies, Virginia rose by 16 percent—a positive sign—but less than half the national growth of 34 percent—so a difference of 18 percentage points. The result is that, in the recent period of economic recovery, Virginia is falling further behind the nation, not only in overall industry R&D, but in that highly valuable R&D for new product and process developments paid for by industry's own sources of revenue.

Figure 9. Percentage Growth of Industry Research Funding by Source, Virginia and U.S., 2010 to 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.

Virginia's economic policies are moving in the right direction to address this need for increased investment by companies in R&D from their own sources for advancing new product development. In 2016, Virginia significantly expanded its R&D tax credit. A key change was the creation of a new Major R&D tax credit for companies undertaking $5 million or more above a base amount that is set at 50 percent of the average of the past three years. This new Major R&D tax credit has a rate of 10 percent and an annual limit across all companies filing of $20 million. This is additional to the existing traditional R&D tax credit, which is refundable so that early-stage companies without profits can benefit. The traditional R&D tax credit was also enhanced by: (1) being raised to a maximum of $45,000 per company up from

$35,000; (2) offering two ways to calculate the credit with an alternative that helps increase the base though lowers the rate from 15 percent to 10 percent; and (3) increasing the cap from $6 million to $7 million.

Still, the weakness of Virginia's industry funding of R&D activities from its own revenues to further new product development is persistent. Historically, there has been only one year in which the amount of R&D tax credits applied for under the traditional credit exceeded the amounts available.[14] In fiscal year (FY) 2016, the first year of the changes in state's R&D tax credits, only $4.7 million was claimed of the $27 million allocated.

Discussions with industry stakeholders suggest that, for individual companies, especially emerging product-oriented companies, the refundable R&D tax incentive is a significant benefit, though limited by the $45,000 cap. Going forward, it will be important to monitor whether the addition of the Major R&D tax credit is effective.

Still, given the importance of industry in driving innovation-led development, enhancements to the R&D tax credit alone are not likely to be sufficient. Industry also needs to be able to leverage the presence of a vibrant and industry-facing university research base as a competitive advantage offering expertise and talent, access to shared-use labs, and new technologies ready for commercialization.

Unfortunately, this points to the next two significant challenges facing Virginia.

Challenge: Strengthening university capacities in technology transfer and commercialization, while growing its research base with more team-based, translational research centers.

The rise of many state and regional economies in innovation-led development has been fueled by the presence and activities of university research capabilities in supporting broader industry-led innovation development, from start-up company formation, new product development of existing firms, and a stronger clustering of related advanced industries. The National Research Council in its 2013 report, Best Practices in State and Regional Innovation Initiatives: Competing in the 21st Century, explains as follows:

> A key factor in the rise of the United States as a technological power has been a long tradition of close ties and frequent collaboration between companies and a network of first-rate universities. Underlying the success of innovation clusters such as Silicon Valley, Route 128, and the Research Triangle of North Carolina are local universities with a longstanding mission of spurring economic development by developing technology with and transferring technology to local industry and stimulating the creation of new businesses in university-centered incubators and science parks. Technology-intensive companies commonly locate their operations near the best universities in particular fields of science and engineering in order to enable their internal research departments to work with "star" scientists and to recruit promising students.[15]

14 *See Cherry Bekaert analysis of new R&D tax changes in Virginia at http://www.cbh.com/guide/new-credit-opportunities-for-virginia-businesses/.*

15 *Charles Wessner, Editor, Best Practices in State and Regional Innovation Initiatives: Competing in the 21st Century, National Research Council, National Academies Press, 2013, page 49.*

One direct measure of the contributions and industry-facing orientation of universities and federal labs is how well they are performing through formal technology transfer activities involving not only the generation of new inventions leading to patents, but also the licensing of that IP to existing companies or to new start-ups that are launched on the basis of that IP.

A national database of technology transfer activity is maintained by the Association of University Technology Transfer Managers (AUTM). AUTM provides insights to how Virginia's major research universities stack up to their peers. Over 2010 to 2016, Virginia's three largest research universities—UVA, Virginia Commonwealth University, and Virginia Tech—reported consistently each year to AUTM. Together, these three research universities comprised 78 percent of all university research activity in 2015 (latest year available). These three universities also comprise 79 percent of all start-ups formed, 85 percent of licensing revenue generated, and 97 percent of the licenses executed, according to the most recent annual plans submitted by universities to SCHEV.

Compared with the national average of all universities reporting to AUTM, Virginia is generally above average. The state stands higher in disclosures of new inventions, licenses issued, and licenses by patent issued, while standing comparable on start-ups generated. The three large Virginia universities fall behind the nation in the level of patents issued (which may reflect resources available for covering patent costs) and gross license income generated (which often reflects having one major winner that can skew licensing income, plus how universities trade-off licensing income for industry-sponsored research) (Table 2).

Table 2. Technology Transfer Metrics for Virginia's Three Largest Research Universities Reporting to AUTM, Compared with Average of All U.S. Universities Reporting, 2010–2016, per $10 Million of University Research

Metric	Average of Virginia's Three Largest Research Universities	Average of All U.S. Universities Reporting to AUTM
Disclosures per $10 Million of Research	4.41 (3,401 total)	3.72
Patents Issued per $10 Million of Research	0.66 (508)	0.92
Licenses Issued per $10 Million of Research	1.11 (854)	1.04
Licenses per Patent Issued	1.68	1.13
Gross License Income per $10 Million of Research	$91,557 ($70.6 m)	$351,546
Start-Ups per $10 Million of Research	0.13 (101 total)	0.14

Source: TEConomy Partners' analysis of AUTM survey.

The trends for technology transfer activity among the three largest universities in Virginia show a significant rise in the past two years in disclosures, patents issued, licenses, and gross license income. While not the highest among the prior years in start-ups, the past two years remain strong with 30 start-ups in total (Table 3).

Table 3. Trends in Technology Transfer Activity for Three Largest Research Universities in Virginia, 2010–2017

Metric	2010	2011	2012	2013	2014	2015	2016	2017
Disclosures	388	396	430	439	437	385	495	485
Patents Issued	67	73	61	54	73	65	71	117
Licenses Issued	100	92	85	95	102	123	146	145
Gross License Income	$9.6 m	$9.9 m	$9.5 m	$5.8 m	$7.8 m	$7.0 m	$11.6 m	$11.5 m
Start-Ups Formed	9	9	12	13	14	22	13	17

Source: TEConomy Partners' analysis of AUTM survey and data provided by universities for 2017.

Still, there is considerable room for improvement in the practices used across Virginia's research universities in their technology transfer and commercialization efforts. On a positive note, the policies for technology transfer at Virginia universities appear fairly consistent with national best practices in terms of how to handle IP, conflict of interest, and faculty incentives.

A separate assessment of university technology practices sets out 34 recommendations for improving technology transfer and commercialization, with its main areas of focus on advancing translational research and commercialization practices. The types of improvements that can strengthen Virginia's university technology transfer and commercialization include providing more technical and market expertise input into how inventions are assessed before patent decisions are made; undertaking more invention lead prospecting with proven entrepreneurs walking the halls; increasing the access to proof-of-concept projects for de-risking university technologies; creating more streamlined templates and transparency in deal-terms; and better connecting with entrepreneurs, venture investors, and other stakeholders as the commercialization process unfolds and new start-ups are formed.

Individual universities are at different stages in addressing these modern approaches to more "market-driven" technology transfer and commercialization practices. The challenge is how to go beyond having each university do it on its own, and finding ways to scale up efforts that are working at individual universities statewide. This is particularly important since there are many smaller research universities without the resources or staffing to take on these improved practices. Pursuing these more market-driven technology transfer and commercialization processes also calls for more clarity in state policy on the goals the Commonwealth seeks from university technology transfer—short-term revenue maximization from IP management that places the emphasis on quick wins or longer-term value creation for advancing the state's economic development that calls for more emphasis on commercialization activities leading to start-ups and connections to existing businesses in Virginia.

So, the overall assessment based on metrics and a review of policies and practices is that research universities in Virginia have the active technology transfer efforts underway with the basic infrastructure of policies, staffing,

and organization to be a good bet for generating increasing translation with focused, collaborative efforts to address improvements in technology transfer and commercialization practices.

However, another part of the equation on raising results from technology transfer and commercialization needs to be considered—the size of university research activities in Virginia. Virginia is 25 percent below the national level of university research relative to the size of the economy compared with the nation. In 2015, Virginia's universities generated $2.9 million in research funding per billion GDP, compared with $3.8 million for the nation.

With $1.4 billion in university research funding in 2015, Virginia stands in the middle of the pack of states and far off from the national leaders, who have multiple billions of dollars in university research funding. Virginia's two neighboring states, Maryland and North Carolina, had $3.7 billion and $2.8 billion, respectively, in university research funding in 2015.

While Virginia is growing in its university research base at just ahead of the national average—18 percent for Virginia universities, compared with 12 percent nationally, from 2010 to 2015—it needs to set its sights on being more competitive for federally funded research centers. These federally funded university research centers offer the ability to create the capacities needed for more translational research that is likely to create new IP and engage industry partners, involving team-based, multidisciplinary research able to address solutions, with large-scale shared-use laboratories able to support industry users.

Today, Virginia has some such centers, but compared with Maryland and North Carolina, its weakness across many types of major federally funded research centers available to universities is evident:

- National Institutes of Health (NIH) Center Awards: As reported through NIH, including specialized cores for research centers, Virginia in FY 2017 had 80 awards, while Maryland had 369 and North Carolina 312.

- Engineering Research Centers: Virginia has no active centers, but one self-sustaining graduate. Maryland has two self-sustaining graduates, and North Carolina has three active centers. These large-scale centers across the breadth of engineering disciplines are focused on advancing big solution areas involving significant industry consortia.

- Nanotechnology National User Facilities: There is one at Virginia Tech and two in North Carolina.

- Department of Defense University-Affiliated Research Centers: There are none in Virginia and North Carolina. Maryland has two—one at Johns Hopkins University and one at the University of Maryland College Park.

While the major research universities in Virginia are hard at work advancing larger-scale, team-based research centers, working collaboratively will strengthen their hands.

Challenge: Bridging the disconnect between university research and Virginia-based compay innovation.

At a time when innovation and technology capabilities are driving forces for state and regional economies, the importance of having robust interactions between industry and research universities for propelling innovation-led development is substantial. An examination of numerous studies published in leading economic journals of the relationship between industry innovation and university research expenditures at the state and regional level concluded that "almost without exception, the studies have found a relationship between the measure of innovation and university research performed in close proximity."[16] According to a study prepared for the U.S. Small Business Administration, "Research universities and investment in research universities are major factors contributing to economic growth in the labor market areas in which the universities are situated."[17]

The success of universities in technology commercialization also requires close interaction with industry who can bring a hands-on understanding of the needs of commercial and government markets as well as offering 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 innovation.

Unfortunately, the detailed assessment of Virginia's innovation ecosystem points to the significant gaps in collaboration and engagement between Virginia universities and industry found in sponsored research funding, patent citations, and licensing activities.

One way to gauge industry engagement with university research is through the level of university research funded by industry. In 2015, industry funded $62 million of the $1.4 billion total research funding of Virginia universities. This represents 4.4 percent of total university research funding and is well off the national average of 5.8 percent. One promising sign is that, over 2010 to 2015, industry funding of university research in Virginia rose by 34 percent, outpacing the national gain of 25 percent.

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. Many clinical trials simply involve having a site to recruit patients. But, having a Virginia university/medical center cited with industry as "collaborators," suggesting that they are each helping to guide the conduct of the overall clinical trial, is a distinction of a close industry-university/medical center connection.

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16 Paula Stephan, How Economics Shapes Science, Harvard University Press, 2012, page 214, citing studies from Adam Jaffe et al., "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," Quarterly Journal of Economics, 108(3):577–598; Zoltan Acs, et al., "Real Effects of Academic Research: Comment," American Economic Review 82(1):363–367; Grant Black, The Geography of Small Firm Innovation, Kluwer Academic Publishers, New York; and Corinne Autant-Bernard, "Science and Knowledge Flows," Research Policy 30:1069–1078.

17 Bruce Kirchhoff et al., "The Influence of R&D Expenditures on New Firm Formation and Economic Growth," Maplewood, N.J.: BJK Associates, 2002.

Again, Virginia is found to have a low level of university/medical center collaborations with industry. Among active clinical trials, of 4,682 clinical trials started since 2010 with sites in Virginia, 81 or 1.7 percent represented collaborations of industry with university/medical centers in Virginia.

This lagging level of industry-university research collaborations, though, does not account for the amount of activity taking place with Virginia-based companies. A closer examination raises even greater concerns that the lower levels of industry collaboration with universities overall stem from the lack of close relationships with Virginia industry.

- In university patents developed with industry funding (a window into who is sponsoring university research), out-of-state companies dominate, with 35 of 40 patents involving companies from out of state.

- In citations of university patents (a measure of how closely university innovations are linked to follow-on industry innovations), 303 of 327 industry citations of Virginia university patents were by industry inventors located outside of Virginia. Similarly, for Virginia invented patents associated with federal laboratories/agencies, 417 of 466 industry citations by industry inventors located outside of Virginia.

- In licensing of university patents, out-of-state companies drive licensing activity from Virginia universities, with 108 of 137 licenses issued in FY 2017 going to out-of-state companies.

Discussions with university representatives show that many universities connect with industry in Virginia through pass-throughs of federal R&D projects. For instance, George Mason University reports that industry-sponsored research reached $4.1 million in FY 2017, but pass-throughs from industry involving federal contracts totaled $7.5 million. This engagement with industry on federal research activities suggests that connections are being made between universities and industry, but they are driven by the strong focus of Virginia industry on doing contract research for federal agencies, rather than research funded by companies.

A challenge for growing strong industry-university partnerships is the geographic mismatch of anchor research institutions, located across the state, and the strong concentration of industry innovation, as measured by patents, in northern Virginia. For the four strategic growth opportunity areas, Table 4 presents the leading counties (including independent cities where applicable) in research publications activity and the leading counties in industry-led innovation. With the exception of life sciences, Virginia faces geographic challenges in building industry and university connections across its strategic growth opportunities.

Table 4. Leading Counties and Cities in Virginia in Research Publications Activity and Industry-Led Patenting Activity

Strategic Growth Opportunity Area	Leading Counties and Cities in Research Publications Activity	Leading Counties and Cities in Industry-Led Patenting Innovation Activity
Cyber & Cyber-Physical Security	Montgomery, Fairfax, Charlottesville	Fairfax, Loudoun
Integrated Networking, Communications, & Data Analytics	Montgomery, Charlottesville, Fairfax	Fairfax, Loudoun, Arlington
System of Systems Engineering	Montgomery, Charlottesville, Fairfax, Norfolk	Fairfax, Alexandria, Loudoun, Roanoke City
Life Sciences	Charlottesville, Richmond, Montgomery, Norfolk	Charlottesville, Fairfax, Richmond, Loudoun

Source: TEConomy analysis of Publications and Patent Data

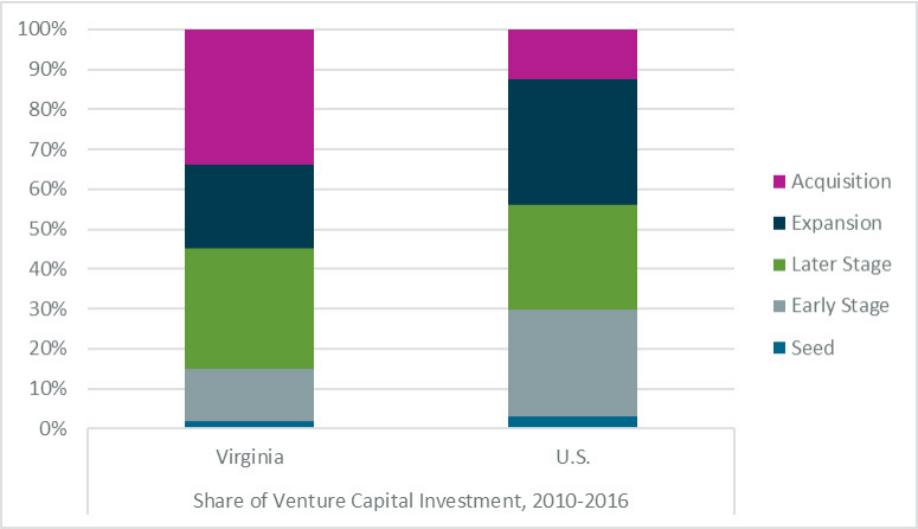
The implications of having such a diverse geographic footprint suggest that Virginia needs to create statewide linkages to maximize its growth potentials for innovation and incorporate strategic thinking to better geographically connect university activity with industry to realize its growth potential in each area.

Challenge: Shoring up entrepreneurial development efforts across regions in the Commonwealth

Of particular importance in advancing a thriving innovation ecosystem are the level and caliber of entrepreneurial development leading to new business start-ups. Starting with David Birch's work, 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 of new companies and job creation rates from those births.

For Virginia, there are clear concerns about the ability to generate early-stage, high-growth companies. In terms of trends, the number of companies funded in Virginia receiving formal venture capital has remained relatively flat. For 2010–2016, Virginia averaged 76 companies, with a high of 87 in 2012 and a low of 70 in 2013. While this is not much different than the pattern nationally, it is disconcerting against the backdrop of lagging growth in venture capital funding. And perhaps Virginia differs from the nation most critically in its low share of venture investment going into early-stage rounds of funding (Figure 10).

Figure 10. Venture Capital Investments by Investment Stage, Virginia and the United States, 2010–2016



Source: TEConomy Partners analysis of Thomson ONE database

While this study did not delve into the regional dimensions of Virginia's innovation ecosystem, it is well understood that the linking of entrepreneurial start-ups to innovation remains a very local phenomenon, where local R&D know-how and entrepreneurial culture need to come together for success.

An examination across the strategic growth opportunities finds that venture capital investment in Virginia is highly concentrated and not finding its way to those regions where the anchor research institutions are based. Table 5 compares the location of research publications activity with venture capital investment activity.

Table 5. Leading Counties and Cities in Virginia in Research Publications Activity and Venture Capital Investment Activity

Strategic Growth Opportunity Area	Leading Counties and Cities in Research Publications Activity	Leading Counties and Cities in Venture Capital Investment Activity
Cybersecurity & Cyber-Physical Security	Montgomery, Fairfax, Charlottesville	Fairfax, Arlington, Loudoun, Alexandria
Integrated Networking, Communications, & Data Analytics	Montgomery, Charlottesville, Fairfax	Fairfax, Arlington
System of Systems Engineering	Montgomery, Charlottesville, Fairfax, Norfolk	Fairfax
Life Sciences	Charlottesville, Richmond, Montgomery, Norfolk	Arlington, Fairfax, Botetourt

Source: TEConomy analysis of Publications and Venture Capital Data

Discussions with the regional technology councils and industry executives reveal distinct innovation needs within each region of Virginia as well as the need to ensure that each region has the capacity to collaborate with its anchor research institutions in advancing innovation-led development. This is not being maximized and presents a major breakdown in Virginia's overall innovation ecosystem.

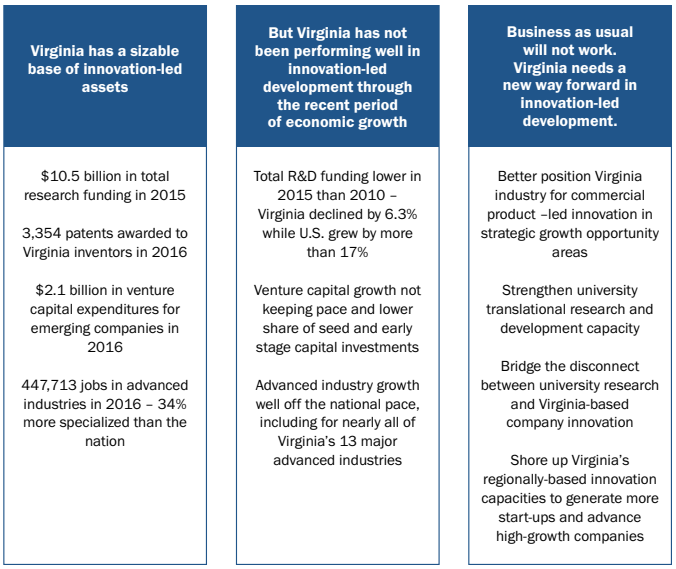
Summary: Going forward, business as usual will not work for Virginia to address its innovation ecosystem needs.

Virginia's underperformance in its innovation ecosystem and the underlying gaps identified suggest that, despite having strengths in R&D core competencies with a line-of-sight to strategic growth opportunities, Virginia's prospects of realizing that growth remain uncertain.

Only by addressing its underlying gaps head-on, with statewide approaches, can Virginia right the ship and regain its course toward innovation-led development.

Figure 11 summarizes the strategic moment facing Virginia and the path forward.

Figure 11. Summary of Virginia's Situation in Innovation-Led Development



D. Strategic Directions: Recommendations for Realizing Growth Opportunities and Addressing Gaps to Drive Innovation-Led Development in Virginia

The challenges identified in Virginia's innovation ecosystem are significant and pose a real barrier to Virginia realizing its full potential in innovation-led development. Addressing these four challenges must become strategic priorities for VRIC. These strategic priorities offer a comprehensive and reinforcing approach for Virginia to address its underperforming innovation ecosystem, and draw upon best practices in innovation-led development from other states to help in informing and designing effective actions to be taken.

It is proposed that VRIC structure its program efforts on four strategic priorities that align with the innovation challenges facing Virginia. The emphasis should be on leveraging and complementing existing efforts while seeking to overcome the identified innovation/entrepreneurial challenges to help catalyze long-term economic growth across the state by focusing on four strategies and an associated set of eight baseline actions and four additional enhanced actions. Specifically, the four strategies seek to accomplish the following:

- Address the low levels and lagging growth of industry R&D from own-company sources that focus on developing new products and services.
- Strengthen university capacities in technology transfer, commercialization, and industry partnerships, while growing its research base with more team-based, translational research centers.
- Bridge the disconnect between university research and Virginia-based company innovation.
- Shore up entrepreneurial development efforts across regions in the Commonwealth.

The strategic directions in this report set out specific baseline actions consistent with the current funding levels for VRIF. The 2018–2019 biennial budget recently proposed by Governor McAuliffe sets an annual budget of $8 million for VRIF.

These baseline actions cover the first three strategic areas set out above involving advancing translational research capacities in the strategic growth opportunity areas in concert with industry engagement, strengthening university technology transfer and commercialization capacity, and bridging the disconnect between university research and

Virginia-based company innovation. The fourth area of activity focused on shoring up regional entrepreneurial and innovation ecosystems is beyond the reach of VRIF's baseline funding, but is a critical complement to the ability of Virginia's regions to leverage the growth potential from their anchor research institutions.

These baseline actions also include ways, when appropriate, to better coordinate with ongoing innovation activities that Virginia supports, including the Virginia Biosciences Health Research Corporation, Commonwealth Health Research Board, and the Center for Innovative Technology. Together, these three programs provide approximately $9 million to $10 million across a broader range of activities than envisioned for the baseline actions for VRIF including basic research, entrepreneurial company development/investment, and technology commercialization. What distinguishes VRIF from these other ongoing, though undersized, innovation efforts are its focus on the following:

- Raising university translational research and commercialization capacities, connecting it more systematically with market-driven processes and focusing it on value creation for economic development in the Commonwealth.

- Comprehensively bridging the disconnect between industry and university research collaborations across translational research, applied research, and technology transfer and commercialization.

Still, in setting out the specific actions for VRIF, it is evident that fully addressing the strategic needs go beyond its current and proposed funding levels. The $8 million recently proposed by Governor McAuliffe in the 2018–2019 biennial budget is significant in terms of Virginia's overall investment in innovation programs; however, when compared with other major innovation states, even with the other ongoing innovation efforts in Virginia added together, the level of funding available is significantly less than in other leading innovation states, such as Massachusetts, Maryland, Pennsylvania, Colorado, and Texas.

To more fully meet the challenges facing Virginia, an enhanced set of actions are also set out as part of the strategic directions for this research asset assessment study for the Commonwealth to consider. These enhanced actions far outstrip the resources available to the Virginia Research Investment Committee by creating the organizational capacity to take on a greater scale of activities and involve broader public-private partnership efforts.

Table 6 provides a summary of the recommended action plan to address the strategic priorities set out, including baseline actions for VRIC to consider and enhanced actions for the Commonwealth's leadership and key stakeholders to consider.

Table 6. Recommended Action Plan: Baseline Actions for VRIC to Consider and Enhanced Actions for the Commonwealth to Consider

Strategy One: Pursue the strategic growth opportunities through public-private collaborations in advancing translational research capacities

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 1: Establish a competitive translational research project fund involving industry and university partners in strategic growth opportunities	**Enhanced Action 1:** Support the formation and sustainment of industry-led statewide translational research centers in each of the strategic growth opportunity areas
Baseline Action 2: Raise Virginia's competitiveness to pursue major federal research center awards to multi-university, multi-industry collaborations through planning, program coordination, and outreach grants and offering matching state funds for facility and equipment costs	

Strategy Two: Strengthen University Technology Transfer and Commercialization Capacity

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 3: Seek legislation that clarifies state policy on goals of university technology transfer and commercialization and set out clear metrics for measuring value creation	**Enhanced Action 2:** Create a dedicated statewide Virginia research commercialization and new ventures development organization to advance promising university and federal lab technologies
Baseline Action 4: Advance a new multi-university and federal lab consortium with industry mentors to target proof-of-concept funding in the strategic growth opportunity areas, learning from the Virginia Innovation Partnership pilot	
Baseline Action 5: Provide programmatic funding to advance collaborative university approaches in technology transfer and commercialization	

Strategy Three: Bridge the disconnect between university research and Virginia-based company innovation

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 6: Support an industry R&D portal across Virginia research universities in strategic growth opportunity areas to tap university shared-use laboratories and expertise	**Enhanced Action 3:** Broaden the dedicated university technology commercialization and new ventures development organization to create a more robust and proactive industry partnerships component
Baseline Action 7: Establish a statewide competitive matching grant program for applied industry-university research projects for small- to mid-sized companies with projects in strategic growth opportunity areas	
Baseline Action 8: Support regional showcases of university innovations in strategic growth opportunity areas	

Strategy Four: Shore up Virginia's regionally based innovation capacities to generate more start-ups and advance high-growth companies

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline funding resources not able to address this strategic need separately from support for statewide development	**Enhanced Action 4:** Create a network of Virginia Regional Innovation Partnerships

Strategy One: Pursue Strategic Growth Opportunities through Public-Private Collaborations in Advancing Translational Research Capacities

Strategic Need for Virginia

The four strategic growth opportunities identified through the line-of-sight assessment in Virginia reach broadly across the state's research assets and base of advanced industries in offering a diverse mix of growth prospects for development. These four strategic growth opportunities include the following:

- Cyber and cyber-physical security
- Integrated networking, communications, and data analytics
- System of systems engineering solutions
- Life sciences.

Further consultation with industry executives, development organizations, and academic leaders, as well as a review of market research studies, show that each strategic growth opportunity has its own targeted development pathways that address specific development challenges (see Appendix A for more details). Across the four strategic growth opportunity areas, there are two common underlying challenges in implementing strategic development plans for jump-starting and sustaining growth:

- Each broad innovation platform is being held back by a combination of Virginia's lower levels of industry research activity or gaps in university research capacities.

- While industry's own-source funding of research is low in Virginia and lagging national growth averages, university research activity in Virginia has few major federally funded research centers that offer the large-scale facilities and team science that can support the translation of research to advance commercialization and industry partnerships.

Although some progress has been made to address these challenges by individual universities in the state, a more comprehensive statewide approach focused on targeted development pathways for innovative growth opportunities can address both these issues as well as the unique needs of specific university and industry stakeholders in each area.

Ongoing Virginia Innovation Development Activities

While there is no comprehensive focus on advancing development pathways in strategic growth opportunity areas for Virginia, two efforts focused on translational research efforts in a targeted technology area have been established and can be leveraged:

- Virginia Biosciences Health Research Corporation (VBHRC) is a nonprofit organization authorized by the General Assembly in 2013 to advance translational medicine and commercialization. While its governing board is university led, VBHRC seeks out strong industry partnerships. One broad, statewide collaboration among

universities, hospital systems, and industry that VBHRC has launched is a targeted initiative in neurosciences to advance new translational research capabilities, such as a clinical research network to rapidly screen and enroll participants for clinical trials, leveraging a shared neurological disorders registry. VBHRC has also advanced an inventory of available shared-use facilities across neurosciences and facilitated a statewide shared resources agreement across seven research universities in Virginia to provide reciprocal access on the same basis and cost as the university housing the shared-use laboratories. The challenge VBHRC faces is limited funding to deepen its efforts in broad collaborative translational life sciences development.

- The Commonwealth Center for Advanced Manufacturing (CCAM) is another public-private partnership effort focused on translational research, with specific capabilities to advance applied research in advanced materials for manufacturing. Since its opening in late 2012, CCAM offers a dedicated state-of-the-art shared-use facility and an in-house technical team to work collaboratively with its industry and university partners on production-ready innovation, coupling that effort with a focus on workforce and talent development. Specific technology focus areas include adaptive automation systems, surface engineering, and additive manufacturing. Going forward, UVA and Virginia Tech have committed to add 11 new faculty members at each engineering school to strengthen and broaden engineering capabilities relevant to CCAM and a second research center called the Commonwealth Center for Aerospace Propulsion Systems (CCAPS). Virginia State University has agreed to work closely with CCAM on the hiring of faculty and research faculty in areas related to advanced manufacturing.

Just getting underway is another collaborative research center in life sciences, the Global Genomics and Bioinformatics Research Institute, involving a collaboration of Inova with research universities in Virginia. Thus far, UVA and George Mason University are initial university collaborators.

Actions to Pursue:

- Baseline Action 1: Establish a competitive translational research project fund involving industry and university partners in strategic growth opportunities
- Baseline Action 2: Raise Virginia's competitiveness to pursue major federal research center awards to multi-university, multi-industry collaborations through planning, program coordination, and outreach grants and offering matching state funds for facility and equipment costs
- Enhanced Action 1: Support the formation and sustainment of industry-led statewide translational research centers in each of the strategic growth opportunity areas

Baseline Action 1: Establish a competitive translational research project fund involving industry and university partners in strategic growth opportunities

One approach to advancing translational research is to directly provide matching funds for multi-industry partners to collaborate on addressing areas of specific innovation needs. Often, a key need across industry is to put in place shared-use labs and testing facilities. In other cases, it is to conduct precompetitive research into important industry topics that will benefit multiple companies.

An added value of offering funding for translational research projects that reach beyond an individual company is that it spurs stronger industry networking and identification of common needs that university partners can work on collaboratively with industry to address.

The awards should be made on a matching basis and involve projects in the $50,000 to $250,000 range. Key selection criteria should include the following:

- Industry-identified need and/or support
- Likely direct economic impact
- Project scope and approach to innovation
- Project team and resources
- Realistic budget and finances.

A key to the success of this effort is to have a strong outreach component. It is recommended that VRIC should work through key intermediaries, such as the regional technology councils, GO Virginia regions, and regional accelerators, to facilitate proposal generation. This might include having SCHEV staff be involved in holding workshops; making presentations at industry networking events and other public meetings; and being available to provide technical assistance on the goals, requirements, and criteria.

The Maine Technology Institute's Cluster Initiative Program offers competitively awarded grants aimed at addressing broader translational and technology deployment needs of Maine's high-potential technology-intensive clusters. It supports the success of Maine businesses through joint work of companies, service providers, research laboratories, and educational institutions by funding infrastructure or common programs that help them collectively to be more competitive, develop new products and services, and reach new markets. Since its start in 2002, the program has made more than 100 awards totaling more than $17 million helping create or support multiple companies in targeted sectors of Maine's technology-based industries. The program is funded at $1-2 million annually, with grants ranging from $50,000 to $500,000. Competitions are held multiple times during the year and small grants are assessed on a rolling basis. The awards require a 1:1 match, but this may be in the form of equipment or in-kind services in addition to cash match.

Examples of multi-industry collaborations funded by MTI in targeted technology sectors include the following:

- Multiple projects supporting the Gulf of Maine Research Institute in its efforts to support and sustain Maine's traditional seafood cluster through the development and expansion of a sustainably harvested certification program for the Gulf of Maine seafood and to tackle the difficult issue of traceability of seafood by piloting a full supply-chain collaboration from harvester to food service sector.
- Maine's Advanced Engineered Wood Composites project involving a broad collaboration of Maine companies, researchers, and industry organizations to develop and commercialize biopolymers from potatoes and forest biomass.
- A new Composites Engineering Research Laboratory (CERL) for the Maine Composites Alliance to create a world class polymer-characterization applied research facility in Maine with capabilities that include applied engineering expertise for manufacturing, process development, and optimization; complete, advanced analytical services; focused educational training; and prototype manufacturing. The industries presently served by CERL include marine composites, construction and structural composites, aerospace and avionics composites, wind and hydrokinetics composites, transportation composites, polymer resins development, thermoplastic and thermoset resin manufacturers and processors, electronics packaging and semiconductors, and other consumer composites.
- An effort in precision machining involving an expansion of the University of Southern Maine's School of Applied Science, Engineering, and Technology's Manufacturing Applications Center in order to better serve Maine companies in their efforts to improve and commercialize new technologies, products, and processes.

VRIF Resources Required: Assuming an average of $150,000 to $175,000 per project, the goal should be to support approximately 15 projects annually, requiring approximately $2.5 million in annual funding.

Baseline Action 2: Raise Virginia's competitiveness to pursue major federal research center awards to multi-university, multi-industry collaborations through planning, program coordination, and outreach grants and offering matching state funds for facility and equipment costs

Large-scale federally funded research centers offer universities the ability to support translational research capacities ranging across multidisciplinary fields that are well-suited for industry collaboration in ways that individual faculty research grants simply cannot. But, the competition is stiff. The process involves considerable planning and outreach to be successful, often well ahead of the start of the proposal process. In fact, many universities with a history of such centers learn to concentrate on influencing the focus of future research centers and also build up the capacity to effectively compete, including the research administration staff assisting with program coordination and facilitating partnership development.

Despite Virginia being a leading innovation state with a hefty level of R&D activities, Virginia's research universities do not have a successful track record in pursuing such major federally funded research centers. Success in the future will likely take the collective strength of Virginia's research universities, which raises the challenges for planning and program coordination. While the dollar figure is not large for supporting the planning, program coordination, and outreach efforts needed for success, it can pay off with significant dividends. These efforts to advance the planning and program coordination to pursue major federally funded university research centers should be aligned to the strategic growth opportunities.

Solid planning and program coordination, however, is also not sufficient. States are learning that they need to be able commit state funding to match the federal as well as industry investment, typically funding capital projects, such as facilities and equipment. VRIC should collaborate with other state and private funding partners to be able to offer matching grants for attracting federally funded university research centers to Virginia.

Massachusetts Technology Collaborative, a state quasi-public corporation charged with growing Massachusetts' innovation economy, offers a Collaborative Research and Development Matching Grant Program to support large-scale, long-term projects that have the potential to spur innovation, promote cluster development, and grow jobs by investing in critical R&D infrastructure. These investments support R&D partnerships that bring together the Commonwealth's world-class research institutions and class-leading companies. All proposals must include collaboration among two or more universities or research institutions.

By allocating matching funds to support capital expenditures, the Innovation Institute works with an Investment Advisory Committee composed of executives from academia, industry, and the venture capital communities to identify opportunities to strengthen and expand the state's innovation economy, with a specific focus on technology clusters where Massachusetts can achieve global leadership.

Summary of current R&D awards:

- $20 million in awards made since 2014, with millions more committed in matching contributions;
- Five awards made to projects across the Commonwealth, helping support innovative industry-academic collaborations and R&D infrastructure; and
- Emerging industries supported: cloud computing, marine robotics, printed electronics, cybersecurity, nanomaterials/smart sensors.

Plus, through MassTech's University Match Fund, existing federally funded research centers gain support to build the capacity to link R&D to the needs of business and industry and to support technology commercialization.

VRIF Resources Required: The goal should be to annually support three to five planning activities to pursue major federally funded university research centers. Up to $100,000 in funding should be provided for staff resources and travel costs. The staffing could involve paying for release time of a key faculty member or for bringing on a consultant.

Regarding state commitment of matching funds, VRIC could use some of its state bonding authority to collaborate with other state and private funding partners to develop an approach that would enable the capital funding to pursue matching funds for federally funded university research centers. A $1 million to $2 million reserve capital fund should be available at any time to support this effort.

Enhanced Action 1: Support the formation and sustainment of industry-led statewide translational research centers in each of the strategic growth opportunity areas

An enhanced activity for Virginia that has proven to pay significant dividends across the nation is to advance translational research centers that address the full ecosystem needs for advancing a strategic growth opportunity. This statewide organizational approach to pursuing strategic growth opportunities offers the advantage of supporting strategic approaches to realizing opportunities, while bringing together multiple industry partners and higher education institutions.

By focusing on a specific area of development that encompasses multiple projects and multiple organizations, targeted development initiatives in specific growth opportunities have shown the ability to accomplish the following:

- Advance world-class "basic to translational" research and innovation capacity, with a strong focus on building university research capacities through hiring of eminent scholars with a proven record of industry collaboration and investments in shared-use laboratory facilities.

- Attract and generate top graduate student talent and broader technical workforce needs of industry.
- Foster the growth of existing firms, creation of new firms, and attraction of firms.

These innovation needs would focus on advancing "industry-facing" research activities and specialized shared-use facilities to advance new product development and commercialization through active connections to serial entrepreneurs, angel investors, and seed-stage venture capital funds.

Additional benefits of these dedicated technology organizations are their ability to support the following:

- Branding and proactive outreach that creates and sustains a market leadership position for Virginia and helps generate business attraction leads for Virginia.
- Addressing workforce and new talent generation from development of new curriculum and degree programs at the postsecondary level to experiential learning and internships that connect students with industry to creating career academies, summer programs, and career awareness at the K–12 education level.

Learning from Oregon Inc. and the North Carolina Biotechnology Center, it is important for accountability and ensuring strong economic development connections that each of the targeted development initiatives be advanced as an industry-led, nonprofit organization, with representation of state government and participating Virginia universities and other higher education partners.

The selection of translational research centers to advance the strategic growth opportunities should be based on a competitive process that evaluates proposed activities from joint industry-university consortium applicants. The following should be among the criteria to be considered:

- The economic growth potential of the initiative to create high-wage jobs in Virginia;
- How the initiative will provide a competitive advantage for Virginia;
- The potential of the initiative to leverage private and federal funding; and
- How the proposed activities address real needs for advancing the emerging opportunity in Virginia.

One long-standing example is the North Carolina Biotechnology Center. North Carolina legislature in 1984 took the lead in establishing a dedicated, private, nonprofit, industry-led development organization for advancing biotechnology, with the formation of the North Carolina Biotechnology Center. The Center represented the world's first government-sponsored commitment to advancing biotechnology-based economic development with a focus on public-private partnerships and filling key gaps to ensure the growth of this industry in the state. Over the years, NCBiotech became the state's key mechanism to catalyze life science industry development working across the full ecosystem of programs. The Center is focused on developing the biotechnology sector statewide by supporting research, business, and education. NCBiotech provides funding for collaborative research projects, financial assistance in the form of grants and loans to early-stage bioscience companies, and support for an array of bioscience education initiatives. The NCBiotech also offers more soft-support efforts that serve as a connective tissue for growing biotechnology in the state with: portals and other assistance aimed at connecting early-stage companies with larger corporations, venture financiers, angel capitalists, and university licensing offices; an industrial fellowship; monthly networking forums and an annual in-state biotech conference; listings of available commercial wet-lab space; and entrepreneurial education produced in cooperation with the Council for Entrepreneurial Development. NCBiotech has also been instrumental in business attraction of biosciences companies for North Carolina. It serves as the marketing arm that helps identify and qualify leads.

The results of NCBiotech have been outstanding, and it has been integrally connected to North Carolina's leading position in biosciences industry development. NCBiotech now generates more in state and local tax revenue from the early-stage companies it invested in that are still active in North Carolina than it receives in state funding, which stands at between $15 million and $20 million annually.

Oregon through the Oregon Innovation Council used a competitive state grant process to advance larger-scale industry-university research and innovation consortia, known as Signature Research Centers, in targeted strategic growth areas. The state funding enabled the formation of industry-led research and innovation organizations, involving multiple companies and multiple universities. Perhaps the most successful one is the Oregon Nanoscience and Microtechnologies Institute (ONAMI) representing a collaboration of four Oregon universities (Oregon Health and Science University, University of Oregon, Oregon State University, and Portland State University), a national laboratory (Pacific Northwest National Laboratory), industry, and the investment community. Among its activities is providing matching funds for federal and private collaborative research projects, enabling industry access to a collection of university-based shared-user facilities, and furthering commercialization and new company formation. ONAMI points to several key successes in its first decade:

Through its sustained support of coordinated shared-lab facilities at universities and collaborative research efforts of under $25 million, ONAMI has spurred nanoscience and microtechnology university research in Oregon from $9 million back in 2004 to consistently above $30 million annually, with total funding of over $360 million through 2015.

Industry support of university research has been significant, growing to $36 million in equipment, facilities, and services.

45 business start-ups were generated with ONAMI support of $7.9 million in commercialization gap funding, leveraging an additional $165 million in follow-on funding from private investment and SBIR funding.

VRIF Resources Required: For this transformative initiative to be in line with efforts such as Oregon Inc., it should be funded at a level reaching approximately $12 million to $15 million annually involving a mix of operating and capital investments. Each targeted development initiative would be funded up to $5 million annually and should be able, after three to five years, to demonstrate significant levels of matching funds being generated from its program efforts as well as broader development returns from its activities to qualify for continued funding. It is expected that two to three target development initiatives would be ongoing by the end of year three.

In the initial years of the program, Virginia might consider planning grants of up to $100,000 for initial proposals to be able to develop more specific business plans that address market, competition, program activities, strategic positioning and risk assessment, financial plan, etc.

Strategy Two: Strengthen University Technology Transfer and Commercialization Capacity

Strategic Need for Virginia

Technology transfer activities across Virginia's major research universities are actively being pursued and generally measuring up to national averages in key measures of disclosures, licensing, and start-up activities. Plus, recent years have shown continued improvements in many measures of technology transfer activity.

Still, there is considerable room for improvement. Industry stakeholders are concerned about the barriers to accessing university IP and advocate for more streamlined and business-friendly approaches. Each university seems to have its own approaches, and there is an interest in creating more effective and business-friendly approaches shared across all universities in Virginia. Another related concern is that universities are viewing their IP as a significant source for generating revenues rather than as a resource for advancing economic development in the Commonwealth.

Three key findings emerged from the detailed assessment of Virginia research universities' practices and policies in technology transfer, commercialization, and industry partnerships leading to value creation:

- Virginia's public research universities are caught between conflicting goals of short-term "revenue maximization" versus "value creation" for the Commonwealth that maximizes efforts to start-up companies, supports growth of existing companies, and attracts outside companies.

- Funding is limited for de-risking technologies and engaging in market-driven translational research that is important not only for generating start-ups, but also for engaging Virginia companies in research partnerships and licensing activity. The funding that does exist within the universities today is primarily focused in the life sciences.

- Wide-ranging and significant opportunities exist for increased collaborations in technology transfer practices and resources across Virginia's universities, which not only can benefit smaller research universities that lack resources, but also can create a business environment for collaborating with industry that is more streamlined and predictable.

In addition, by advancing Virginia to be a national leader in technology transfer and commercialization, the deeply rooted R&D disconnect between Virginia industry and its universities, which includes lower levels of industry engagement across joint publications, licensing, and industry participation in research consortia, can be addressed.

Ongoing Virginia Innovation Development Activities

While state support is limited for de-risking technology, the following entities provide some level of funding:

- The Center for Innovative Technology (CIT), through its Commonwealth Research Commercialization Fund, provides 1:1 matching funds for de-risking technologies from universities. Over the past two years, covering FY 2016 and FY 2017, $1.4 million was provided annually in matching funds, which assisted 13 projects on average annually. The funding is targeted to a set of strategic technology areas identified by CIT in consultation with regional technology councils and others on a regular basis.

- The Virginia Biosciences Health Research Corporation offers translational research grants, which serve to help de-risk technologies, which require two university partners and at least one industry partner. In 2015 and 2016, approximately $2.85 million was invested each year, supporting six to seven projects annually. While the required match is 1:1, requiring an industry partner involved has increased the match to closer to $2 in match for every $1 of public funding. VBHRC also reports substantial levels of follow-on funding across all of 24 translational research grants it has funded, reaching $77 million against total VBHRC funding of $20 million.

Actions to Pursue:

- Baseline Action 3: Seek legislation that clarifies state policy on goals of university technology transfer and commercialization and set out clear metrics for measuring value creation

- Baseline Action 4: Advance a new multi-university and federal lab consortium with industry mentors to target proof-of-concept funding in the strategic growth opportunity areas, learning from the Virginia Innovation Partnership pilot

- Baseline Action 5: Provide programmatic funding to advance collaborative university approaches in technology transfer and commercialization

- Enhanced Action 2: Create a dedicated statewide Virginia research commercialization and new ventures development organization to advance promising university and federal lab technologies

Baseline Action 3: Seek legislation that clarifies state policy on goals of university technology transfer and commercialization and set out clear metrics for measuring value creation

The emphasis of Virginia's university technology transfer and commercialization in the years ahead needs to be on value creation to advance economic activity in the Commonwealth. Across the nation, research universities are evolving their technology transfer efforts, according to a recent study from the Association of Public and Land-Grant Universities, to respond to "the needs of the innovation economy—and in particular their local economies—by including innovation, entrepreneurship, and "economic engagement" programming in their strategic planning processes."[18]

18 *Association of Public and Land-Grant Universities, "Technology Transfer Evolution: Driving Economic Prosperity," November 2017, page 3.*

Stating this as a state policy goal will provide a clear message and focus for university leadership to set out more explicit goals and approaches for how they will encourage and advance new company formation locally, along with broader industry research partnerships and increased licensing with Virginia companies.

There is precedent for doing this in Virginia. Virginia bills HB 134 and SB 259 were passed in 2006 and codified into law (Code of Virginia § 23-4.4), giving Virginia universities greater flexibility in transfers of IP. These bills allowed public research universities in Virginia to provide more preferential terms to companies in licensing technology in return for sponsored research arrangements, or what is referred to as an "IP-Modified Sponsored Research Agreement."

To keep a focus on this goal of value creation, it should also be addressed by universities in their six-year strategic plans that are submitted to SCHEV.

VRIF Resources Required: None

Baseline Action 4: Advance a new multi-university and federal lab consortium with industry mentors to target proof-of-concept funding in the strategic growth opportunity areas, learning from the Virginia Innovation Partnership pilot

One weakness identified in Virginia's current technology transfer and commercialization efforts across all research universities interviewed—from the well-resourced to the least-developed in terms of technology commercialization capacities—is the lack of proof-of-concept funding for de-risking university technologies to advance proof-of-concept funding, especially outside of the life sciences.

Proof-of-concept funding is most effective when it is carried out as part of a more integrated commercialization process. The process of commercializing research discoveries to the marketplace is a highly complex, interactive, and market-driven process that calls for enhancing research discoveries into technology solutions to meet the need(s) of customers in the marketplace. It involves a number of activities, such as assessing the technology and its potential markets against current products in the marketplace, e.g., technology and market assessments. It involves proof-of-concept of the viability of the technology, and optimizing its engineering and design to meet price points of the marketplace to enhance the potential for sales and growth. For successful start-ups, it involves identifying and recruiting the business and management team and securing the sources of investment or financing that will carry the product and/or firm through various stages of growth and development toward becoming an established company/product in domestic and global markets.

A high-value approach to proof-of-concept funding across universities that offers hands-on mentoring and engagement with venture capital investors was successfully piloted in Virginia over 2012–2014 through a U.S. Economic Development Administration (EDA) grant, known as the Virginia Innovation Partnership (VIP). VIP involved nearly all of Virginia's research universities and was managed by UVA, Virginia Tech, and SRI International. This effort targeted support for 20 proof-of-concept projects annually through a competitive request-for-proposal process, supported by a mentoring network of private-sector experts and linked to venture investors, including a major annual event to pitch

those projects that supported forming new company start-ups. The results of VIP were very promising—147 proof-of-concept ideas submitted from 12 Virginia universities, with 36 projects funded and completed, 21 patents filed, 2 trade secrets established, and 12 new start-ups formed that raised $4.3 million over the 2012–2014 period of the grant.

The value-added of the VIP effort was its high level of engagement with business mentors to advance technologies through the proof-of-concept process—and not only be members of a "selection" panel—and the strong connectivity with a Virginia university's technology transfer office so that the technologies advanced can be integrated into broader commercialization efforts by the university.

A similar effort should be undertaken that leverages lessons learned during this pilot program and seeks additional resources and funding to re-start a similar initiative that is used to create a national brand around this Virginia capability—effectively advertising to the industry and investment communities that Virginia's innovation pipeline is more substantially de-risked and investment worthy than is typically found in universities across the nation. Ideally, this effort would be done in collaboration with the university-targeted portion of CIT's Commonwealth Research Commercialization Fund.

VRIF Resources Required: The original EDA grant for the VIP was $500,000 annually matched by $725,000 from collaborating universities and sponsors. VRIC might consider augmenting this level to $1 million a year, if matching funds are available from the universities and other stakeholders.

Baseline Action 5: Provide programmatic funding to advance collaborative university approaches in technology transfer and commercialization

Virginia universities are already beginning to find ways to be more collaborative in pursuing common goals for enhancing their research capabilities and approaches to technology commercialization. The recently signed shared-resource agreement for accessing shared-use labs forged by VBHRC is a clear sign, as well as the VIP pilot.

VRIF can be an important resource for ensuring these collaborative efforts are catalyzed. The detailed review of technology transfer and commercialization policies and practices identified many opportunities for meaningful collaboration that can be aided with existing program support from the VRIF, including the following:

- Establishing common templates and deal terms across Virginia universities that are vetted with industry and venture-capital representatives.

- Advancing multi-university access to "master agreement" relationships negotiated by individual Virginia universities, so that the collective strength of Virginia's universities can be tapped in meeting the needs of a company that are beyond an individual university's research capabilities. An effort in this regard is currently being developed with multi-university collaboration with MITRE, which manages a number of federally funded R&D centers, spurred by MITRE's interest in broadening its access to university research expertise as it serves its national security clients.

- Collaborating across Virginia's technology transfer offices to establish a statewide network of business advisors currently being tapped by individual university technology transfer officers and potentially augmented to assist in the assessment of university inventions and the identification of key questions to be addressed in de-risking the technologies and to serve as advisors in follow-up commercialization efforts.

- Establishing shared programs across Virginia's universities for entrepreneurial training programs and business plan competitions for graduate students/postdocs in fields of research associated with the strategic growth opportunities.

Example of Shared Services for Business and Technical Experts to Assist in University Technology Transfer and Commercialization: Innovation Center for the Rockies

Founded in 2005, the Innovation Center for the Rockies (ICR) became a valued entrepreneurial support organization for university technology transfer offices in Colorado. ICR's niche was in leveraging a network of hundreds of advisors in the business community to help university technology-transfer offices and researchers understand the business potential of their innovations. ICR would then help develop commercialization strategies for those innovations, sometimes matching entrepreneurs with the technology to launch companies. ICR has commercialization agreements with the University of Colorado Boulder, Colorado State University, and the Colorado School of Mines.

ICR has developed a database of more than 1,500 screened and qualified advisors in Colorado and other states with specific technology domain expertise to support local early-stage companies and to inform the commercial assessment of university technology and guide its commercialization approach, including connecting it with investors and management teams. To help directly support the commercialization of high-potential technologies, the Innovation Center has organized an angel network.

The Innovation Center has generated significant results. It created 13 companies from university technologies, generating nearly 500 jobs and $171 million in revenues. It helped attract more than $90 million in new capital. Plus, in its critical role in supporting university technology assessments, the Innovation Center has worked with hundreds of research teams to commercialize their technologies.

The cost of operating ICR stood at approximately $300,000 annually, but the business model of supporting operations with funding from the university partners, corporate sponsors, and the City of Boulder was not sustainable. ICR in early 2017 merged with Innosphere, an incubation organization with facilities in Fort Collins and Denver that had a strong track-record of success in using entrepreneurs-in-residence (EIRs) and corporate partners to help start-ups hone their business plans and become investor-ready in a focused two-year program.

ICR is now fully merged into Innosphere, which continues to offer the same university technology transfer support programs, led by ICR former staff, plus now offers Innosphere a Boulder location for its broader entrepreneurial incubation programs.

As part of this effort to pursue collaborative approaches, VRIC might consider supporting the development of regional technology commercialization resource centers in areas where a shared resource could be particularly useful in creating a critical mass of deal flow, translational research networks and resources, investor and partnership development initiatives, and technology development and deployment initiatives focusing on regional economic development priorities and industry clusters. A pilot initiative in Norfolk serving ODU, Norfolk State University, and the Eastern Virginia Medical School is suggested due to the proximity of these institutions, their expressed desire to explore mechanisms to partner more effectively in technology commercialization and in innovation and

entrepreneurship, and their shared focus on leveraging innovation and research assets to help drive economic development in their region.

These collaborative services, short of pursuing Enhanced Action 2 for a new university technology commercialization entity in Virginia, can be advanced through SCHEV, including the use of consultants or grants to universities to help in administering on behalf of all universities. SCHEV could engage the Virginia Innovation Alliance, which involves Virginia's eight largest research universities and medical schools to promote common interests for improving university technology commercialization. or the re-instituted VIP to assist with coordination of these collaborative efforts, if needed.

VRIF Resources Required: Up to $250,000 of funding is proposed annually to advance collaborative projects across universities. Many of these collaborative efforts will not require significant costs, but having some funding to support the time and expense of pursuing specific collaborative tasks can be very helpful in moving things forward since it can also help create real time frames for completing the work. In the case of the suggested regional technology commercialization resource center in Norfolk to be piloted, funding of up to $150,000 is recommended to be matched by the universities served.

Enhanced Action 2: Create a dedicated statewide Virginia research commercialization and new ventures development organization to advance promising university and federal lab technologies

The opportunity to create a comprehensive organizational approach to provide more advanced resources for university technology commercialization stands as a major enhancement that VRIF could champion.

A key building block of the broader organization approach to university technology commercialization is to advance a more integrated approach to proof-of-concept funding that fully integrates mentors and advisors into the process, as piloted under VIP. Plus, this organization can offer a more hands-on approach to advancing the collaboration services and provide a level of transaction focus and program management that the baseline efforts cannot.

The organizational approach should go beyond just proof-of-concept funding and be able to move seamlessly into follow-on seed funding to form new start-ups commercializing university technologies, as is being done by Georgia's GRA Ventures effort. This recognizes that proof-of-concept funding alone is not sufficient to advance university technology commercialization. The "valley of death" between IP creation and new product introduction has widened in the last decade. The challenge for university technology commercialization after a successful proof-of-concept project is to take the next step toward a new firm start-up. Most technology transfer and commercialization offices can be supportive of new firm start-ups, but lack the ability to be a catalyst in advancing the start-up process. By combining proof-of-concept funding with access to follow-on seed capital for forming the business, the organizational approach for university technology commercialization can provide a substantial value-added component and can link these new start-ups more effectively to reach private-sector investors, in collaboration with CIT's venture investment support programs to attract their first round of institutional investor funding.

Example of Seamless Approach from Proof-of-Concept to Seed Funding: Georgia Research Alliance's GRA Ventures Program

The focus of GRA Ventures is on starting up new companies from university research through identifying promising technologies, conducting due diligence, and supporting proof-of-concept and venture start-ups. It provides for a rigorous and staged assessment of commercialization potential and offers milestone-oriented funding with initial grants of up to $50,000 to assess commercial feasibility followed up with matching grants of up to $100,000 for prototype development and new venture development involving loans of up to $250,000. To facilitate the process, GRA supports "VentureLab" managers at each participating campus, who focus on recruiting and overseeing the efforts of serial entrepreneurs to move the VentureLab process forward. Recently, GRA Ventures added another new program component for GRA Industry Fellows. These GRA Industry Fellows are being recruited from across the United States, often tapping into alumni from Georgia's research universities, who have had a proven career in technology and entrepreneurial companies. It was undertaken to address the difficulty of finding qualified management teams locally, especially for bioscience companies.

This GRA Ventures model has a demonstrated track record. GRA reports that, since 2002, GRA Ventures has accelerated the formation and launch of university-based start-ups by accomplishing the following:

- Evaluating more than 900 university technologies and inventions
- Advancing to market 250+ distinct university technologies with multiphase commercialization grants totaling $17 million
- Providing $10 million in low-interest loans to 42 of the most promising companies.

Today, 100 active university-based companies have received crucial support from GRA Ventures. These enterprises have brought to Georgia more than a half-billion dollars in equity investment. They have also generated more than $300 million in revenue, and today they employ more than 600 professionals.

Perhaps the most critical addition the organizational approach can provide is to create an effective team and network of entrepreneurs-in-residence (EIRs) to support university technology transfer and commercialization. For the translational research stage of moving IP through commercialization, the need is to better activate hands-on guidance to inform the commercialization approaches for translating university research discoveries. Across universities, there is a growing use of EIRs to provide this more engaged and intensive approach to help inform commercialization efforts. EIRs are experienced entrepreneurs who are retained by the technology transfer offices to advise and assist faculty and students as they explore the commercial viability for research discoveries and inventions.

The effective use of EIRs goes well beyond just the commercial assessment of technologies and the coaching of faculty and students. EIRs are particularly effective in prospecting for inventions by walking the halls of research facilities to learn about the expertise of researchers in the labs and about the research questions being addressed to determine if they may have significant commercial relevancy—and so offer a better way to bring out inventions than simply relying on faculty themselves. Plus, EIRs can often be a resource for networking with the larger investment and entrepreneurial community in a focused and value-added manner, and so increase the prospects of successfully commercializing a university technology and forming a new start-up company or collaboration with an existing venture.

The detailed assessment of university technology transfer and commercialization policies and practices found that EIRs were used by some, but not all, of Virginia's research universities. For those Virginia universities using EIRs, most are very limited efforts with only one or two EIRs covering the entire research enterprise. Plus, few universities in Virginia are engaged in proactive prospecting for inventions through ongoing contact with individual investigators in their labs. EIRs could make an important difference in this regard.

It is recommended that a team of EIRs be a cornerstone of the new organization formed to support university technology commercialization. This team should have strengths in each strategic growth opportunity area that can be deployed to assist Virginia's universities in advancing the commercialization of technologies.

Under the direction of each of Virginia's research universities, the team of EIRs should be available to assist in lead prospecting, market and technical assessments, and defining the scope of proof-of-concept projects. For larger universities, a jointly funded resident EIR hired as part of the university technology transfer team might be advanced who would help to coordinate the team approach for commercialization. It is expected the approach to having these resident EIRs would be tailored to each of the major research universities (with at least $100 million or more in annual funded research).

But, the primary function of the EIRs will be to engage at the stage of commercialization as new start-ups are formed. These EIRs would help in developing the business plans, attracting strategic partners and investors, and building out the product development team. The goal is to have these EIRs join start-ups if appropriate and, when the time is right, come back into the organization to support future start-ups. This process has worked effectively at a number of technology development organizations, including the Pittsburgh Life Sciences Greenhouse.

Example of Use of EIRs: Pittsburgh Life Sciences Greenhouse (PLSG)

As a dedicated organization focused on growing emerging life-science companies, PLSG combines incubation and early venture financing with a successful effort to advance entrepreneurial talent to lead life science innovations. From 2001 to 2017, PLSG has worked with over 470 companies, and has made approximately $22 million of direct investments to 80 companies, which has leveraged over $1.5 billion of additional capital for the region. One of the keys to PLSG's success—that addressed a significant challenge for the region—is an EIR program, which was started to provide emerging life-sciences companies with domain-specific, C-level leadership, providing executive talent to help form companies; subject matter experts to guide companies; executives to run companies; and program managers and directors to help companies grow. In 2005, the PLSG expanded the EIR Program to extend its areas of support and to add specialists for the life sciences community that will work more directly with institutional and private investors and the venture capital industry at large—and renamed it the Executive Program. Since inception, 48 executives have participated in the PLSG EIR program, with more than 60 percent of them still in the region working directly with a life science company. The importance of the Executive Program is that the 30 companies that now employ former PLSG EIRs make up a large share of the 80 life sciences companies that PLSG has invested in over its 15+ years.

VRIF Resources Required: To support the activities of the new university technology commercialization organization, $5 million to $7 million of annual funding is needed, far beyond the capacity of VRIF. It is expected that the costs of operating the organization, including EIRs, would amount to close to $1.5 million. The additional $3.5 million to $5.5 million would involve the investment activities of the organization in proof-of-concept, prototyping, and seed funding for business formation.

Strategy Three: Bridge the Disconnect Between University Research and Virginia-Based Company Innovation

Strategic Need for Virginia

Virginia needs a campaign to raise the level of activity and engagement with industry to promote R&D focused on new product and process development to serve commercial markets. VRIF can provide a means to further university engagement with industry to create a stronger context in which industry taps existing state incentives for R&D and begins to complement the strong focus on serving federal contract R&D needs with a parallel focus on industry investment to advance new product and process developments.

This assessment of the innovation ecosystem points to the significant gaps in collaboration and engagement between Virginia universities and industry found in joint publications, patent citations, licensing activities, and university-industry consortia. The major way universities connect with industry in Virginia is through pass-throughs of federal R&D projects, which is not oriented on advancing new product or process developing that serves broader needs of economic development.

Another challenge for growing strong industry-university partnerships is the geographic mismatch of anchor research institutions, located across the state, and the strong concentration of innovative companies in northern Virginia, which holds back maximizing growth from commercialization to scale-up activities. Therefore, a more focused approach to open up universities is needed.

For industry-university partnerships to take root, they must be driven by results. Information-sharing and relationship-building activities are foundational, but they fail to drive the bottom line for industry interest and involvement—i.e., generating new products, sales, and jobs. In today's global knowledge economy where innovation drives competitive advantage for industry, this means that the research capabilities and technology advances of academia must be matched to the short-term, time-sensitive and product-driven needs of industry.

Ongoing Virginia Innovation Development Activities

There is little in the way of efforts in this area beyond the presence of industry R&D tax credits, which offer a higher tax credit to companies that work with universities on research projects.

Actions to Pursue:

- **Baseline Action 6:** Support an industry R&D portal across Virginia research universities in strategic growth opportunity areas to tap university shared-use laboratories and expertise

- **Baseline Action 7:** Establish a statewide competitive matching grant program for applied industry-university research projects for small- to mid-sized companies with projects in strategic growth opportunity areas

- **Baseline Action 8:** Support regional showcases of university innovations in strategic opportunity growth areas

- **Enhanced Action 3:** Broaden the dedicated university technology commercialization and new ventures development organization to create a more robust and proactive industry partnerships component

Baseline Action 6: Support an industry R&D portal across Virginia research universities in strategic growth opportunity areas to tap university shared-use laboratories and expertise

Raising awareness and building relationships are foundational building blocks for establishing stronger collaborations between industry and academia. It is recommended that VRIF support the development of a portal for industry seeking to identify university research and innovation resources as a critical "infrastructure" for building collaborations.

Web-based tools are valuable, especially in offering information on shared-use labs including their capabilities and costs and in cataloging expertise of faculty with an interest in collaborating with industry on research projects; but, these information-sharing tools are a passive form of engagement. The cornerstone of the recommended portal for industry is having "site miners" at each university to sustain this industry partnership effort. These site miners would be the industry-facing representatives of Virginia's research universities across the strategic growth opportunity areas.

These site miners need to offer a high-touch service function that is highly responsive to industry and faculty clients for sponsored research activities and works to sustain long-term relationships with companies.

The specific roles of the site miners will be to conduct proactive outreach to industry through company site visits as well as offering technology symposia and regular workshops with regional technology councils and other industry associations, helping to coordinate industry requests for research collaborations that come out of these efforts, and building relationships with faculty and research centers seeking to grow in industry research collaborations and offering industry access to shared-use labs.

The approach would be for VRIF to co-invest with each research university to support a site miner to advance industry partnerships across the strategic growth opportunities. It is critical that these site miners be experienced industry executives with scientific expertise, who have worked with universities while in industry and possess know-how in business development. These site miners need to be viewed as strategic, outward-facing resources and so need to have a line of reporting to each university's lead for research administration.

Key to the success of each site miner is the ability to assess the industry requests and offer a value-added service of matching to specific faculty and to other university resources with the expertise to address the needs of the company. Being university-wide will enable unbiased outreach to all faculty who can meet specific industry needs. All industry requests need to be handled in a timely manner—one leading university has a 24-hour turnaround goal for all industry requests—and that should be the intent of the site miners.

If access to master agreements is opened up across all of Virginia's universities, then the site miners would be the logical point of contact as specific industry needs are identified that go beyond the services of an individual university.

The effectiveness of site miners would be well-served by having the enhanced actions implemented to form industry-led organizations in the strategic growth opportunity areas and/or create the university technology commercialization organization with a focus on industry partnerships as suggested below.

In the absence of these enhanced organizational efforts, it is recommended that these site miners collaborate across their universities facilitated by SCHEV to share a common, internal, common-customer resource planning tool that tracks company inquiries and ongoing activities, as well as having a coordinated approach on web-based information sources on shared-use labs and the expertise of faculty seeking industry-sponsored research relationships. This might be facilitated through the Virginia Innovation Alliance, which involves Virginia's eight largest research universities and medical schools to promote common interests for improving university technology commercialization, or the University-Based Economic Development consortium, which is a larger grouping of over 60 universities and economic development stakeholders focused on advancing university linkages with economic development.

Example of Use of Site Miners for Building Collaboration: Consortia for Improving Medicine with Innovation & Technology (CIMIT)

A successful collaborative initiative that has broadly embraced the use of site miners is the Consortia for Improving Medicine with Innovation & Technology (CIMIT), a clinically based consortia of Boston-area hospitals and engineering schools that supports translational research by multidisciplinary teams for medical device and clinical technology applications. CIMIT involves physicians from Harvard teaching hospitals who collaborate with scientists and engineers from the Massachusetts Institute of Technology, Charles Stark Draper Labs, Northeastern University, and Boston University, as well as a wide range of industry partners.

CIMIT demonstrates that it is possible to systematically facilitate the process of addressing real market opportunities through innovative technology solutions. It engages with clinicians and industry to define key areas of focus.

Of CIMIT's facilitation roles, the use of site miners is most unusual, inventive, and productive. These individuals have proven to be the key to penetrating the multiple isolated member institutions and to connecting people and ideas across the cultural walls of these institutions and even across the boundaries separating departments within them. They literally "mine" the institutions for projects and people deserving CIMIT's attention and help.

Site miners at academic and research institutions open and maintain dialogues with the clinicians and researchers at the front lines of healthcare and technology within their institutions. Site miners at companies and foundations look for strategic opportunities for their organizations to engage and help address an important business opportunity or organizational mission. Site miners across the consortia work with each other.

The CIMIT approach is described in detail at http://www.cimit.org/documents/210422/220498/Venture+Findings+featuring+the+CIMIT+Model/8e27dae0-8fd5-4eeb-a5e2-24556a967c56.

VRIF Resources Required: Approximately $1 million of matching grant funding to co-sponsor site miners with research universities in Virginia should be established. A sliding scale might be considered based on the size of the university's research funding, but no university should receive less than $50,000.

Baseline Action 7: Establish a statewide competitive matching grant program for applied industry-university research projects for small- to mid-sized companies with projects in strategic growth opportunity areas

A proven means of fostering greater industry-university collaborations in applied research to address market needs of companies is a matching grant program. Such programs help build relationships between academic researchers and companies and provide support for activities that may lead to investments of private capital and commercialization of new technologies.

In the first wave of state technology development programs in the 1990s and early 2000s, matching grant programs for applied industry-university research were common. As of 2008, 28 states had matching grant programs that provide an incentive for firms to support research projects at local research institutions.[19] In the wave of "entrepreneurial development" focus for state technology development programs, many of these applied industry-university research programs were swept aside. But, the experience of states such as Maryland, with its continued support of the Maryland Industrial Partnerships Program, is that they can have long-term impact and assist not only existing companies, but emerging ones (see text box).

The State Science and Technology Institute in its Resource Guide for Technology-based Economic Development, prepared with support from the EDA, identified two keys to success of these matching grant programs for industry-university applied research projects based on interviews with individuals with experience in designing, managing, and operating these efforts:

- One key to a successful program is being able to match companies with the right faculty member. Companies may know what research problem they need addressed but they often do not know how to find a university researcher with the appropriate capabilities. Serving in this matchmaking capacity is an important role for the staff administering the grant program. It should also be recognized that not every faculty member is interested in conducting applied research projects for industry clients. It is critical to find those that are interested in collaborating with companies and in providing real world experiences for students.

- Another factor of success is that funding needs to be sufficient to attract the attention of faculty members. Faculty will not be interested in writing proposals for very small projects, particularly if they can get larger amounts of funding from other sources. One program director indicated that he felt that grants must be a minimum of $40,000 to $50,000, with the expectation of additional funding of up to $250,000 to get the attention of faculty.[20]

Having in place the site miners will allow Virginia universities to serve the first key success factor.

For the second success factor, it is recommended that projects be funded up to $100,000 in equal matching support, with the opportunity to have a follow-on project for up to $100,000 more in matching funds be approved on an expedited basis upon hitting critical milestones in advancing the applied research effort. Small businesses, defined

19 Technology, Talent and Capital: State Bioscience Initiatives 2008, http://www.iowabiotech.com/econ_dev_reports/Battelle_State_Bioscience_Initiatives_2008.pdf.
20 A Resource Guide for Technology-based Economic Development, prepared by the State Science and Technology Institute for the EDA, August 2006.

by either size of employment or revenues, would be able to fulfill the match using in-kind resources, while larger companies would need to meet their match on a dollar-for-dollar basis of support for the research project.

There should be an open process for submitting projects so that these efforts can move forward in a reasonable time frame. The funding would then need to be provided on a first-come, first-serve basis. Each funded project would need to demonstrate both technical soundness and a realistic pathway to impacting economic development.

Example of Matching Grant for Industry-University Applied Research Partnerships: Maryland Industrial Partnership Program

The Maryland Industrial Partnerships (MIPS) Program, administered by the University of Maryland, provides up to $100,000, matched by the company partner, for university-based research projects that help companies develop new products. MIPS projects help companies find solutions to technical challenges, as well as develop products, processes or training materials. MIPS projects are conducted by university faculty and graduate students in conjunction with company researchers. An assessment of MIPS, prepared in 2017, found that over a 30-year period it supported 1,185 joint university-industry research collaborations and leveraged $46.2 million in state funding with $145 million in industry direct and in-kind funding. 187 companies reported having current employment associated with MIPS-supported technologies. This resulted in $4.7 billion in product sales, supporting 7,150 jobs in Maryland for 2017.

VRIF Resources Required: Approximately $3 million of matching grant funding for industry-university applied research projects is recommended to support 30 to 45 projects annually.

Baseline Action 8: Support regional showcases of university innovations in strategic opportunity growth areas

Many of Virginia's major research universities and federal labs are located far from the concentration of its major industry technology hub in northern Virginia. This geographic mismatch makes university research collaborations with industry difficult.

While offering site miners and applied research grants is helpful, it is recommended that annual showcases of university innovations in strategic growth opportunities be held across the state to better raise industry's awareness of the collective strength of universities in these key areas.

These regional showcases would be undertaken by SCHEV in coordination with the Virginia University Based Economic Development officers group around the strategic growth opportunity areas. These events would be coordinated with the regional technology councils and would tap the industry networks being advanced by the site miners.

In structuring these regional showcases of university innovations, best practices from a range of national conferences should be tapped, including using poster sessions and facilitated networking and allowing for sign-ups for one-on-one discussions.

VRIF Resources Required: Approximately $200,000 for these annual regional technology showcases should be budgeted, including covering costs of the conference space, production of collateral materials, outreach marketing, and honoraria for keynote speakers.

Enhanced Action 3: Broaden the dedicated university technology commercialization and new ventures development organization to create a more robust and proactive industry partnerships component

The effectiveness of site miners, soliciting interest for applied research grants, and hosting regional technology showcases would all be best served by having an organization supporting these efforts. It is recommended that the proposed university technology commercialization organization create an industry partners program component. This would strongly complement its knowledge and involvement with university technologies and spin-off companies, enable it to serve as a matchmaker for strategic partnerships with existing advanced industry companies with a presence in Virginia and, in turn, augment its capabilities to seek out corporate investment and partners for emerging companies involving university research.

VRIF Resources Required: No additional funding beyond that set out for the baseline actions is needed. Instead, it would be consolidated as part of the operations of the new university technology commercialization and industry partnerships organization.

Strategy Four: Shore Up Virginia's Regionally Based Innovation Capacities to Generate More Start-Ups and Advance High-Growth Companies

Strategic Need for Virginia

Discussions with the regional technology councils and industry executives reveal distinct innovation needs within each region of Virginia as well as the need to ensure that each region has the capacity to collaborate with its anchor research institutions in advancing innovation-led development. Innovation and entrepreneurial development is a contact sport, so it is only through stronger regional innovation and entrepreneurial development that research strengths found across anchor research institutions can be tapped for statewide development.

At the same time, the flat level of emerging companies receiving venture capital and the lower share of venture funding going toward early-stage venture capital investments in Virginia suggest that more shots on goal are needed for Virginia to successfully rev up its entrepreneurial economy. States and regions with thriving entrepreneurial sectors share one characteristic—they are home to a risk capital community that is both oriented toward early-stage financing and committed to indigenous investment. Entrepreneurs require access to capital at each stage of their development, from early-stage, proof-of-concept and prototype development to Series A and B venture financing. States that have limited risk capital in which to invest end up leaving their entrepreneurial companies on the "runway" unable to take off and reach their growth potential. Emerging trends in innovation capital are making it even more imperative to have indigenous funds for the growth of innovative firms. These indigenous funds help in identifying promising discoveries and technology advances, providing the initial funding to validate these opportunities, supporting the formation of new ventures, and providing the on-the-ground capacity to support these new ventures and facilitate their connection to outside venture capital.

Ongoing Virginia Innovation Development Activities

There is a statewide resource for early-stage investments and an emerging network of technology accelerators, but not a systematic approach to serving the full regional needs for entrepreneurial development in Virginia:

- CIT Growth Accelerator Program (GAP) Fund makes seed-stage investments in high-potential, early-stage technology companies. In FY 2016, the Commonwealth appropriated $3.1 million for the GAP Fund program, of which $2.6 million was invested in 16 Virginia high-tech start-ups. In FY 2017, CIT invested $2.4 million in 33 Virginia high-tech start-ups. In terms of impacts, from FY 2004 to FY 2017, CIT invested a total of $22.9 million in 181 companies. CIT's investments leveraged $584 million in additional angel and venture capital investment, and the 181 client companies have generated 1,497 jobs. Of these 181 companies, 27 have failed and 8 have moved out of state. One hundred fourteen of the 181 companies (nearly two-thirds) were still operating in Virginia and 32 companies had been acquired or had paid back CIT.[21]

21 Innovation and Entrepreneurship Investment Authority and Center for Innovative Technology, "FY2017 Report on Broadband, the Growth Accelerator Program (GAP) and the Cyber Security Accelerator (MACH37™)," Report Document 263, 2017. https://rga.lis.virginia.gov/Published/2017/RD263/PDF.

- The MACH37 cybersecurity accelerator was launched in FY 2013 to stimulate growth of the cybersecurity industry by supporting and attracting very early-stage companies to Virginia and leveraging private investment. The 90-day accelerator program accepts two cohorts of five to eight companies in the fall and spring and awards $50,000 to graduates. The program received a $2.5 million appropriation from the Commonwealth to support program design, recruitment, operations, and seed funding the first two years. Notably, the MACH37 accelerator and the MACH37 seed fund were designed with the goal of private sector sustainability. Since FY 2017, MACH37 operations and seed funding have become self-sustaining through private sector investments. In the four years of MACH37 operations, FY 2013–2016, 35 companies graduated from the program, and 24 of the 35 companies are still operating in the Commonwealth. There have been no successful exits to date, and no failures.

- Lighthouse Accelerator in Richmond, Virginia, is a nonprofit, mentor-driven start-up acceleration program connecting promising founders with proven mentors, investors, support services, working space, and lean start-up education to move from idea to viable high-growth venture in three months. Since 2012, it reports that it has helped launch 27 start-ups, all of whom are still in existence, and generating $5.5 million in revenues. It has also achieved strong leverage on its $340,000 in direct funding awarded to its start-up companies, who have then gone on to attract $9.5 million in follow-on investment.

- A new accelerator for the Roanoke-Blacksburg region, known as the Regional Acceleration and Mentoring Program or RAMP, was launched in the spring of 2017. Partners in the initiative include the City of Roanoke, which renovated RAMP's home in the historic Gill Memorial Hospital building; the Roanoke-Blacksburg Technology Council, which recruits RAMP participants and provides them mentorship and networking opportunities; and Virginia Western Community College, which provides business education training on site. A state grant of $600,000 was used to fit out the accelerator facility.

Actions to Pursue:

- **Enhanced Action 4:** Create a network of Virginia Regional Innovation Partnerships

Enhanced Action 4: Create a network of Virginia Regional Innovation Partnerships

Virginia needs to bring new entrepreneurial development tools to serve its regional economies. The diverse nature of these regional economies requires a flexible approach in which local stakeholders have a key role in governance and oversight to serve the needs of anchor research universities as well as local entrepreneurs.

The issue facing these communities is to create not a silo of resources, but an effective approach that links entrepreneurial development efforts to build the "farm club" of firms with access to indigenous sources of seed capital in a seamless manner as key business formation milestones are reached. This stage of funding, which usually requires $250,000 to $2 million in individual investments, constitutes a critical private-sector market gap for investment dollars as the size is usually too small for larger venture funds to consider. The presence of strong indigenous investment funds is needed to attract outside regional and national funds to invest in Virginia.

It is recommended that an approach like Ohio's network of entrepreneurial service providers and complementary local seed funds be advanced in Virginia. For those regions, such as Richmond and Roanoke, that have launched technology accelerators and entrepreneurial providers, this can help augment and sustain their efforts. For regions that are still planning these efforts, these tools can set them on the right path.

Example of Building an Infrastructure of Regionally Based Entrepreneurial and Investment Services: Ohio Third Frontier's Network of Entrepreneurial Service Providers and Seed Funding Capitalization Program

The state of Ohio, through the Ohio Third Frontier, has demonstrated that, in a state with a very diverse set of regions, it is possible to advance tools that can serve its regions in building the infrastructure of entrepreneurial support organizations and seed funding tailored to their specific needs.

To support entrepreneurs within each region of Ohio, a network of six entrepreneurial support provider organizations (ESPs) has been put in place. These ESPs must be non-profits and have strong local and regional participation in governance and oversight. Entrepreneurial services focus on direct hands-on assistance to high-growth technology companies primarily through mentor networks and EIRs. Because each ESP also has its own pre-seed/seed fund, companies within the portfolio often receive both services and risk capital investments.

Ohio has also made significant investments to build its indigenous early-stage, risk-capital base through the Ohio Third Frontier Pre-Seed/Seed Plus Fund Capitalization Program (PCFP). The goals of the Ohio Third Frontier PCFP include the following:

- Increase the number of professionally managed Pre-Seed Funds investing throughout Ohio;
- Increase the amount of early-stage capital being invested in Ohio technology-based companies;
- Create a risk capital climate that supports the development, retention, and attraction of investable technology companies in Ohio; and
- Build a pipeline of technology company deal flow that increasingly attracts the resources of venture capital firms both within and outside of Ohio.

The Ohio Third Frontier had invested approximately $65 million in over 44 pre-seed and seed funds across the state of Ohio. These funds, in return, have leveraged over $3 billion in follow-on funding and have created nearly 5,000 jobs.

Oversight by state is focused on specific performance metrics and return-on-investment analysis. ESPs are also well networked, often sharing best practices, lessons learned, and deal flow as appropriate.

VRIF Resources Required: It is expected that $2 million is needed annually to fund the operations of each entrepreneurial hub established in Virginia to carry out their full efforts in training and mentoring entrepreneurs, providing market and business planning assistance to emerging companies, establishing EIRs to work with their anchor research institutions and emerging companies, engaging with angel investors, and managing a regional seed investment fund.

Each regional entrepreneurial hub should also have at least $2 million a year to invest at the seed stage, seeking to be the first investor, continuing to make investments at the seed stage as milestones are reached with angel investors in the community, and then attracting and participating in the first institutional round (Series A) with venture capital firms, who would likely be located outside of the region. This level of seed funding can be capitalized either up-front or over time. It is expected that a total capitalization of $10 million to $15 million in the regional seed fund would sustain a $2 million level of seed funding annually over time as investments are harvested, with roughly 1 in 10 providing a

significant return on investment, 4 to 5 a minimal return, and the remainder not being able to repay the full principal invested.

It is suggested that four to six entrepreneurial hubs be created in Virginia, with annual operational funding supported by the Commonwealth, requiring $8 million to $12 million annually.

On the seed funding, it is proposed that, over time, half the cost come from the Commonwealth and the other half be raised from the community across foundations, local governments, corporate partners, and individual investors. This would require an additional $1 million to $1.5 million in state investment over a five-year period.

E. Conclusion

The resources from VRIF are strategic, but limited. Table 7 summarizes the baseline actions set out for VRIC's consideration, with recommendations on how the $8 million annually be invested in programs and projects that can be launched over the next biennium. The goal is to reach scale in these baseline actions so that a significant level of activities and at least interim results can be demonstrated by the end of the biennium.

Still, the reality is that the baseline funding for VRIF is simply not up to the task at hand. It is recommended that VRIC help champion a more enhanced approach to bring the sustained organizational approaches needed to spur growth in the strategic growth opportunities through industry-led organizations and create a much-needed dedicated university technology commercialization and industry partnerships organization to work across the universities as well as a new toolset for regional entrepreneurial development.

Table 7. Summary of Recommended Baseline Funding Levels for VRIC to Consider

Strategy One: Pursue the strategic growth opportunities through public-private collaborations in advancing translational research capacities

Baseline Action	Recommended Annual Funding
Baseline Action 1: Establish a competitive translational research project fund involving industry and university partners in strategic growth opportunities	$2.5 million
Baseline Action 2: Raise Virginia's competitiveness to pursue major federal research center awards to multi-university, multi-industry collaborations through planning, program coordination, and outreach grants and offering matching state funds for facility and equipment costs	$100,000

Strategy Two: Strengthen University Technology Transfer and Commercialization Capacity

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 3: Seek legislation that clarifies state policy on goals of university technology transfer and commercialization and set out clear metrics for measuring value creation	$0
Baseline Action 4: Advance a new multi-university and federal lab consortium with industry mentors to target proof-of-concept funding in the strategic growth opportunity areas, learning from the Virginia Innovation Partnership pilot	$1 million
Baseline Action 5: Provide programmatic funding to advance collaborative university approaches in technology transfer and commercialization	$250,000

Strategy Three: Bridge the disconnect between university research and Virginia-based company innovation

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline Action 6: Support an industry R&D portal across Virginia research universities in strategic growth opportunity areas to tap university shared-use laboratories and expertise	$1 million
Baseline Action 7: Establish a statewide competitive matching grant program for applied industry-university research projects for small- to mid-sized companies with projects in strategic growth opportunity areas	$3 million
Baseline Action 8: Support regional showcases of university innovations in strategic growth opportunity areas	$200,000

Strategy Four: Shore up Virginia's regionally based innovation capacities to generate more start-ups and advance high-growth companies

Baseline Action for VRIC to Consider	Enhanced Action for the Commonwealth to Consider
Baseline funding resources not able to address this strategic need separately from support for statewide development	$0

The annual level of activities generated from the baseline actions informed by best practice examples is expected to be significant, including the following:

- Increased industry-university translational and applied research collaborations in the strategic growth opportunity areas, including as follows:
  - 30 to 45 individual Virginia company applied research projects with one or more universities
  - 15 collaborative translational research projects, each involving one or more universities with multiple companies

    - Facilitation of industry engagement and high-touch customer-oriented services through a network of university site miners to work with companies

- Improved university capacity to commercialize their research discoveries, including as follows:
    - 20 proof-of-concept projects with strong industry mentorship leading to 5 to 6 new start-ups annually
    - Streamlined university technology transfer and commercialization practices that place an emphasis on value creation through new start-ups and licensing to Virginia companies
    - Increased capacity through collaborative efforts across universities to share access to market and technical experts and entrepreneurial training.

Beyond the activities generated from putting VRIF's resources to work, several key outcome-oriented measures are suggested to track the direct contributions of the baseline actions, including the following:

- Industry R&D levels generated
- Licensing of university technologies to Virginia companies
- Milestones reached in licensing of university technologies to Virginia companies
- Number of new start-ups
- Follow-on funding to new start-ups
- Evidence of rising valuations in new start-ups
- New sales growth by existing and start-up companies assisted
- Industry rating on quality of services provided.

Appendix A: Detailed Profiles for the Strategic Growth Opportunities

I. Cyber and Cyber-Physical Security

What Is It?

Cyber security involves protection of computer hardware, software, and data from threats ranging from theft to destruction. This rapidly evolving area involves the creation and maintenance of technologies designed to counter threats both proactively and in real time in addition to assessing damage and conducting repairs in the wake of attacks. Many major industries have experienced cyber security attacks in recent years, and given the fundamental importance of databases and networking to modern business processes innovative cyber security technologies will continue to be a key area of active research and development for the foreseeable future. Several key areas that enable ongoing innovation in cyber security solutions include:

- "Security by design" software and hardware solutions
- Vulnerability assessment and testing solutions
- Real-time, massive scale forensic network traffic and computer system activity analysis
- Advancements in encryption, access control, and identity management technologies
- Development of user-behavior analytics modeling
- Cloud and data center infrastructure security

In addition to traditional computer systems, an increasing variety of connected smart devices and infrastructure must also be protected from analogous attacks designed to exploit the architecture of the "Internet of Things" (IoT). As vulnerability becomes an increasing concern for consumer devices connected to the Internet, security will also become an issue for the physical infrastructure and hardware systems that manage public utilities, transportation, medical care, military systems and industrial automation. The ability to provide cyber-physical security solutions for device hardware and infrastructure is an area of rapid growth and high priority for both government and industry to

protect from point of access attacks and includes any devices with embedded microcontrollers that might be able to be compromised by an attacker.

Virginia has a number of research assets developing the next generation of cyber security solutions as well as a significant population of industry and government end users. Additionally, other key growth opportunity areas for Virginia also rely on cutting edge cyber security knowledge to help advance their own applications.

VA Research Innovation Context

Leading Publications Fields with > 1,000 research publications from 2014-2017:

- Computer Science Theory/Methods – 1,494 research publications 2014-2017, 1.32 specialization index
- Computer Science Information Systems – 1,398 research publications 2014-2017, 1.52 specialization index

Additional areas with significant publications activity include Software Engineering and Computer Hardware Architecture.

Themes in Major Grants Activity in Relevant R&D Areas:

- Support for educational programs for training cybersecurity professionals
- Research in new methods of secure data sharing and monitoring cyber-physical systems vulnerabilities

Presence of Major Research Centers/Assets:

- UVA: UVA Link Lab, UVA Applied Research Institute
- VA Tech: Hume Center for National Security and Technology, Advanced Research in Information Assurance and Security (ARIAS) Lab
- GMU: Center for Excellence in Command, Control, Communications, Computing and Intelligence (C4I), Center for Infrastructure Protection and Homeland Security (CIP/HS)
- ODU: Center for Cybersecurity Education and Research (CCSER)
- MITRE

VA Industry Innovation Context

Leading Patenting Areas with > 100 patent records from 2014-2017:

- Network architectures or network communication protocols for network security – 801 patent records, 2.44 specialization index, 1.19 forward citation impact index
- Identity management technologies – 381 patent records, 1.43 specialization index, 1.25 forward citation impact index
- Secure/Encrypted communications technologies – 131 patent records, 1.47 specialization index, 1.56 forward citation impact index

Leading Venture Capital Investment Areas with > $10 million invested from 2009-2016:

- Security/Firewalls and Encryption Software: $609.9 million total equity invested 2009-2016

- Internet Security and Transaction Services: $13.1 million total equity invested 2009-2016

Themes in SBIR Awards Activity in Relevant R&D Areas:

- Security technologies for defense/military networked systems
- Secure short-range communications architectures and encryption
- Device power fingerprinting analytics/modeling for intrusion detection and monitoring

VA Supporting Industry Base Context

Significant industries which support and are end users of innovation in this growth area are found in information technology industries, yet not all firms in information technology are working in cyber and cyber physical security.

An alternative way to see the strength of Virginia in cybersecurity is through specialized analysis of the size of the private industry employment base in cybersecurity. Through a collaborative effort with Burning Glass and CompTIA, the National Institute for Standards and Technology (NIST) maintains the CyberSeek database on employment in cybersecurity jobs. It reports that Virginia as of August 2017 had:

- 66,206 private sector industry jobs in cybersecurity, second only to California's employment base of 80,877.
- the highest concentration of cybersecurity jobs among all states, compared to total private sector employment, with 3.3 times the level of concentration found nationally.

Virginia also has 36 companies with headquarters in the state in the Cybersecurity 500 list, the highest amount amongst states that are a part of the Washington, DC metropolitan region.[22]

Market Potential and Leading Applications

Cyber security markets are becoming intrinsically tied to market prospects of the industries they support embedded solutions for, offering rapidly expanding market prospects in any industry that utilizes data-driven architectures and making it difficult to define distinct market sizes. However, some of the markets for core technology applications in cyber security include:

- North American market for identity and access management systems valued at $5.0 billion in 2016 with CAGR of 15.6%
- North American market for encryption security technologies valued at $8.7 billion in 2016 with CAGR of 13.7%
- North American market for data loss protection solutions valued at $0.7 billion in 2016 with CAGR of 19.4%
- North American market for firewall security systems valued at $2.6 billion in 2016 with CAGR of 17.4%
- North American market for antivirus and antimalware products valued at $10.3 billion in 2016 with CAGR of 11.8%
- North American market for disaster recovery solutions valued at $1.4 billion in 2016 with CAGR of 25.7%
- North American market for risk and compliance management systems valued at $6.9 billion in 2016 with CAGR of 13.7%

22 Cybersecurity Ventures: Cybersecurity 500 List. https://cybersecurityventures.com/cybersecurity-500-list

Some examples of likely market applications aligned with Virginia's research and innovation strengths include:

- Next generation cyber security technologies for integrated networked environments
  - Real-time forensics and intrusion detection solutions
  - User-behavior analytics products
  - Vulnerability assessment
  - Cyber-physical security solutions
  - Embedded systems hardware in defense, energy, and transportation
  - Data center security
  - Real-time monitoring and analytics for networked Internet of Things systems, including SCADA, consumer devices, and medical devices

Key Challenges for Virginia's Innovation Ecosystem

Virginia is already well on its way to embracing this growth opportunity area and fostering signature innovation assets to support ongoing development. However, several challenges to accelerating growth were identified from interviews with research and industry stakeholders which include:

- How to achieve adequate levels of skilled talent supply to meet rapidly increasing demand for cyber security skillsets by industry
- Providing access to Virginia's university research base to local employers in a comprehensive and transparent way
- How to sustain a collaborative environment for cyber security industry given highly competitive government
- How to provide "exits" for entrepreneurially-minded cyber security professionals working in large companies or government to start new companies
- Shifting Virginia economy from cyber security service-oriented companies towards product-oriented companies that are more likely to self-invest in R&D
- Improving strategic partnerships between universities and industry beyond their current level

Potential Development Pathways for Virginia Growth

- Given the recognition of cyber security as a premier opportunity from the state and the momentum generated by recent state initiatives, a key short-term need is supplying skilled labor to meet current industry demand. Development of further initiatives to expand cyber-security talent pipeline should be considered that focus on incorporation of technical certifications and leveraging additional segments of local Virginia population such as returning veterans and retraining of legacy technical talent bases.
- Although industry-university interactions around innovative research have been expanding, it is critical to generate further development of strategic partnerships to inform curriculum development and foster joint research opportunities. Establishing a joint industry-academic advisory group framework for university curriculum development guidelines can help to foster further interaction and embed industry input into producing graduates with well-aligned skill sets. This advisory group can work towards goals of additional certification of Virginia universities as National Centers of Excellence in cyber security research areas.

- Accelerating the formation of new cyber security startups is a key objective in helping to bolster Virginia's ecosystem which currently is more focused around larger defense contracting in cyber security areas. Consider development of entrepreneurial program which incentivize workers in government and larger firms to establish startup businesses through establishing capital financing entity focused on cyber security product companies and de-risking transition to small business careers.
- There is a need to accelerate Virginia's position as a cyber security research hub in a very rapidly moving market space with intense competition from other regions of the U.S. To help further brand Virginia as a desirable destination for cyber security industry and talent, consider signature initiative(s) focused around one or more of the following:
    - Development of a cyber security innovation fund which provides matching state funds to industry in key areas of emerging technology with collaborative university partner requirements
    - Establishment of joint university-industry statewide consortium and associated signature facility that serves as hub for state research efforts and provides access to research ecosystems at satellite institutions focused on cyber security throughout Virginia
    - Establishment of signature shared use "hacker/maker" space for development of cyber-physical technologies outside of DC metro area to help spread industry innovation footprint

II. Integrated Networking, Communications Systems, and Data Analytics

What Is It?

Advancements in the state of connectivity and the ability to process massive volumes of unstructured data have resulted in the need for solutions to address the connectivity and processing power behind modern communications technologies. Today's telecommunications networks rely on a mix of wired and wireless voice and data communications networks, broadband internet networks, and data storage infrastructure that require complex routing and retrieval processes with an ever-increasing user base. Next generation networks will combine all these communications assets with more traditional data processing technologies to create an integrated system that businesses and governments can leverage to provide connectivity and analytical services.

Integrated communications and data networks will provide cutting edge technology solutions that improve multiple aspects of the communications pipeline ranging from:

- Point of access connectivity and speed, particularly wireless technologies designed for secure communications and networking of smart devices and unmanned systems (including defense and "ad hoc" network applications)
- Efficient routing of high volumes of data-driven communications traffic utilizing an interconnected mix of legacy wired, next generation high speed wired, and wireless network node assets optimized at a systemwide level
- Rapid retrieval and processing of "big data" from data storage centers supported by highly automated and secure data center facilities
- Rapid processing of large databases to drive endpoint analytics applications such as machine learning models using on-demand virtual processing resources
- Resilient, distributed infrastructure to support cloud-based services and software in a global market

Virginia has a significant user base of these technologies, particularly in financial technologies (fintech) and government services, as well as a geographical specialization – northern Virginia has one of the largest clusters of data centers in the nation and some estimates indicate that up to 70% of the world's internet traffic passes through the region.[23] Additionally, the area has robust innovation activity across various wireless networking technologies and computer services to support ongoing development of innovation targeted towards building next generation integrated communications frameworks.

VA Research Innovation Context

Leading Publications Fields with > 1,000 research publications from 2014-2017:

- Electrical/Electronic Engineering – 4,304 research publications 2014-2017, 1.16 specialization index
- Computer Science Theory/Methods – 1,494 research publications 2014-2017, 1.32 specialization index
- Computer Science Information Systems – 1,398 research publications 2014-2017, 1.52 specialization index
- Telecommunications – 1,159 research publications 2014-2017, 1.39 specialization index

23 Virginia Economic Development Partnership – Data Centers: Industry Overview. http://www.yesvirginia.org/KeyIndustries/DataCenters

Additional areas with significant publications activity include Artificial Intelligence, Software Engineering, Computer Hardware Architecture, and Applied Mathematics.

Themes in Major Grants Activity in Relevant R&D Areas:

- Research in new methods of managing high performance computing resources
- Establishment of IUCRC's for development of innovative wireless communications network configurations

Presence of Major Research Centers/Assets:

- UVA: UVA Data Science Institute (DSI), Center for Visual and Decision Informatics, Commonwealth Center for Advanced Logistics Systems (CCALS), McIntire Center for Business Analytics, UVA Applied Research Institute, Center for the Management of Information Technology (CMIT), UVA Quantitative Collaborative (QC), UVA Center for Wireless Health
- VA Tech: SyNeRGy Lab, International Institute for Information Technology, Wireless @ Virigina Tech Center, Advanced Research in Information Assurance and Security (ARIAS) Lab, Hume Center
- GMU: Mason Center for Health Information Technology (HIT), Center for Excellence in Command, Control, Communications, Computing and Intelligence (C4I), Center for Simulation and Modeling (Computational Materials Science Center), Center for Distributed and Intelligent Computation, International Center for Applied Studies in Information Technology

VA Industry Innovation Context

Leading Patenting Areas with > 200 patent records from 2014-2017:

- General data analytics and data processing methods – 883 patent records, 0.91 specialization index, 1.05 forward citation impact index
- E-commerce technologies – 482 patent records, 1.40 specialization index, 0.85 forward citation impact index
- Database administration and management – 348 patent records, 1.65 specialization index, 1.10 forward citation impact index
- Network-specific arrangements or communication protocols supporting networked applications – 286 patent records, 1.04 specialization index, 0.83 forward citation impact index
- Electronic payment architectures, schemes or protocols – 251 patent records, 1.67 specialization index, 0.99 forward citation impact index
- Arrangements for maintenance or administration or management of packet switching networks – 226 patent records, 1.93 specialization index, 2.10 forward citation impact index
- Selective content distribution technologies, e.g. interactive television or video on demand – 224 patent records, 0.93 specialization index, 1.47 forward citation impact index
- Local resource management, e.g. selection or allocation of wireless resources or wireless traffic scheduling – 219 patent records, 1.10 specialization index, 2.23 forward citation impact index
- Digital Finance; Insurance; Tax strategies; Processing of corporate or income taxes – 203 patent records, 1.98 specialization index, 0.85 forward citation impact index

- Services or facilities specially adapted for wireless communication networks – 201 patent records, 1.09 specialization index, 1.09 forward citation impact index

Other significant patenting activity in areas focused on management of network traffic, wireless network operations, and software engineering.

Leading Venture Capital Investment Areas with > $10 million invested from 2009-2016:

- Computer Software: $2,479.7 million total equity invested 2009-2016
- Internet Communications: $826.4 million total equity invested 2009-2016
- Wireless Communications: $280.3 million total equity invested 2009-2016
- Internet Content: $271.8 million total equity invested 2009-2016
- Satellite Communications: $151.4 million total equity invested 2009-2016
- Data Communications: $147.8 million total equity invested 2009-2016
- E-Commerce Applications: $133 million total equity invested 2009-2016
- Computer Services: $111.7 million total equity invested 2009-2016
- Internet Software: $89.7 million total equity invested 2009-2016
- Commercial Communications: $21.2 million total equity invested 2009-2016

Themes in SBIR Awards Activity in Relevant R&D Areas:

- Cognitive radio, ad-hoc networks, wideband, and other advanced wireless communications technologies
- Communications protocols and hardware for unmanned systems
- Decision support and simulation modeling tools for military scenario and defense logistics planning
- Image and video analysis tools for real-time analysis and threat detection

VA Supporting Industry Base Context

Significant industries which support and are end users of innovation in this growth area include:

- Computer Systems Design Services – 104,998 employees, 4.35 LQ, 20% growth 2009-2016
- Custom Computer Programming Services – 40,453 employees, 1.84 LQ, 5% growth 2009-2016
- Data Processing, Hosting, and Related Services – 11,286 employees, 1.47 LQ, 1% growth 2009-2016
- Other Computer Related Services – 8,209 employees, 2.89 LQ, 15% growth 2009-2016
- Software Publishers - 4,914 employees, 0.54 LQ, 0.6% growth 2009-2016
- Computer Facilities Management Services – 4,462 employees, 2.66 LQ, -11% growth 2009-2016
- Wireless Telecommunications Carriers - 2,797 employees, 0.89LQ, -33% growth 2009-2016
- Internet Publishing and Web Search Portals – 2,663 employees, 0.51 LQ, 25% growth 2009-2016

Market Potential and Leading Applications

Similar to cyber security markets, integrated networking and communications supports many aspects of modern business operations across the majority of industries. Additionally, data analytics tools and services have become embedded in the way companies deliver their products and services making it difficult to pinpoint a discrete market

space but making it clear that leaders in this innovation space will be able to be at the forefront of growth trends. Some examples of potential markets in this very broad growth opportunity include:

- North American market for software-defined networking (SDN) solutions:
  - SDN configuration technologies market is valued at $484 million in 2015 with CAGR of 80.8%
  - SDN hardware market is valued at $350 million in 2015 with CAGR of 78.3%
  - SDN software market is valued at $199 million in 2015 with CAGR of 117.3%
- North American market for content delivery network hardware technologies valued at $3.6 billion in 2017 with CAGR of 13.6%
- North American market for unified communications and collaboration technology platforms valued at $12.9 billion in 2015 with CAGR of 16.2%
- North American market for "smart city" networked infrastructure management technologies valued at $55.2 billion in 2016 with CAGR of 14.7%
- North American market for Internet of Things enabling technology platforms such as device management and connectivity solutions valued at $224.7 million in 2016 with CAGR of 28%
- North American market for advanced analytics services:
  - Banking and financial services market valued at $22.1 billion in 2015 with CAGR of 1.7%
  - Telecommunications and IT services market valued at $16.1 billion in 2016 with CAGR of 1.3%
  - Life sciences services market valued at $4.2 billion in 2015 with CAGR of 1.7%
  - Transportation and logistics services market valued at $4.3 billion in 2015 with CAGR of 1%
  - Consumer goods and retail services market valued at $9.9 billion in 2015 with CAGR of 1.9%

Some examples of likely market applications aligned with Virginia's research and innovation strengths include:

- Integrated networking solutions
  - Enterprise business virtualization solutions
  - "On-demand" cloud-based infrastructure and distributed computing services
  - Network dynamics monitoring and optimization
- Advanced wireless communications hardware and networks
  - Integrated wireless network infrastructure
  - Wireless encryption and verification
  - Ad-hoc network technologies
- Data center operations [a]nd automation
- Data analytics products and services
  - Decision support tools for government, defense, and marketing industries that leverage integrated machine learning, large data management, and simulation and modeling innovations
  - Digital design, engineering, and testing services
  - Fintech services such as risk management and fraud detection and digital banking solutions
  - Health IT services such as population health modeling, clinical analytics, and bioinformatics
  - Transportation and logistics solutions such as supply chain management and fleet management

Key Challenges for Virginia's Innovation Ecosystem

Virginia has the infrastructure and industry base to achieve success in implementing a next generation integrated big data environment if its innovation strengths can be properly aligned. Key challenges to achieving this alignment that were identified from interviews with research and industry stakeholders include:

- Difficulty in obtaining funding for applied R&D in networking, communications, and analytics in the current environment where early stage assistance is more geared towards defense applications and later stage companies are oriented towards services/operations with less R&D focus
- Lack of meaningful research-oriented consortiums and collaborations between major private companies and universities in the networking and communications space
- Addressing an ongoing skills gap for information technology jobs in broader industries outside of the cyber security space, in particular for data analytics
- Lack of specific identity in data analytics innovation verticals outside of cyber security that can help drive branding and placemaking for Virginia and focus resources towards achieving critical mass in innovation ecosystems
- Conservative investment culture in the state for funding early stage information technology industry companies that incentivizes companies to relocate to succeed
- Need for ongoing implementation of "last mile" connectivity in more regionally isolated regions of the state to complement networking infrastructure strength in metro areas

Potential Development Pathways for Virginia Growth

- A key component of advancing Virginia's position in this area involves building out an ecosystem that emphasizes public-private partnerships to drive innovation. Consider models for expanding university outreach to current in-state companies in this space to help retain critical mass of strength and build out pathways for joint applied R&D efforts.
- Virginia has a unique combination of networking and communications infrastructure assets that can leveraged towards creating a world class innovation environment. Develop a strategic plan for bringing together infrastructure across the spectrum of data centers, transmission lines, and internet networks to create a unique "test bed" environment for open innovation in integrated IT and communications where companies and universities can test real world use cases for next generation technologies.
- The presence of unique data center and transmission infrastructure assets in the state on its own is not enough to drive long term growth - there must also be a focused effort to innovate around these assets. Consider economic development initiatives that incentivize expanding into adjacent markets for data center operations such as business virtualization and automation of cloud infrastructure sites such as targeted recruitment of mid-stage technology companies in these areas and development funds or infrastructure access models for in-state startups.
- The state's innovation strength in wireless technologies should also be a key part of development of an integrated networking and communications ecosystem. Consider developing a network of wireless technologies testing sites throughout the state that build on the initial IUCRC models in this area for use in joint university-industry

pilot projects. The model should leverage partnerships with key faculty to grow talent in this space locally and seek to address regional connectivity challenges where possible.

- Although there are a variety of strength areas for the state in developing innovative data analytics technologies, these centers of excellence need to be more closely aligned with providing R&D outputs for the in-state industry base and develop specialization in key verticals to better brand the state's innovative position. Create strategic plans to brand the state's identity in data analytics research in a few key verticals outside cyber security such as fintech, health IT, or content delivery and focus resources towards research which leverages the state's big data networking infrastructure in these spaces. This may involve realignment of existing university research centers towards more applied work in these key verticals where necessary.
- Using innovative demonstration projects where possible, continue to expand last mile connectivity to more geographically isolated regions of Virginia so industry and research institutions can access the integrated environment.

III. System of Systems Engineering

What Is It?

System of systems engineering (SoSE) is an emerging discipline that combines interdisciplinary engineering and scientific disciplines to design, assemble, and manage complex systems made up of a number of finite components, each of which themselves may constitute a system.[24] As an example, a modern naval vessel will have many different subsystems ranging from propulsion to navigation which are all interconnected through electrical and communications networks and require effective operation by a crew to ensure safety and efficiency. System of systems engineering would employ technologies and approaches to optimize the types and interconnectivity of the different systems found onboard the vessel in an integrated way that captures the complexity of interplay between component systems from the design process through maintenance and repair cycles.

As opposed to traditional systems engineering, which itself is a key supporting discipline for SoSE, the system of systems approach is concerned with an overall system defined by the interactions of various subsystems supporting an overall technology platform rather than focusing on engineering individual components. Because it is principally concerned with integration of many component subsystems, SoSE typically relies on solving networking and interoperability challenges that involve technology areas such as sensors, power electronics, communications, advanced materials, and command and control interfaces. Although SoSE technologies and approaches have traditionally been oriented towards aerospace and defense applications, innovative applications have increasingly been oriented towards automation and unmanned systems in "civilian" areas such as manufacturing, communications and data infrastructure, power grid operations, healthcare delivery, and transportation. Technology areas that are key enablers of the integrated life cycle approach used in SoSE applications include digital design, simulation and modeling, advanced sensing and instrumentation, and distributed computing.

Virginia's innovation assets are particularly well positioned to support ongoing growth in a variety of areas by focusing on the underlying capability of SoSE. Several cross-cutting verticals of innovative activity in Virginia that both rely on ongoing development of SoSE capabilities as well as utilize them in driving technology solutions to market include:

- Atmospheric, naval/ocean, and other environmental sensor systems
- Communications and networking platforms
- Geospatial navigation technologies
- Unmanned systems (aerial, ground, and naval)
- Cyber-physical security
- Transportation systems
- Power electronics
- Engineered Materials
- Advanced manufacturing

24 Jamshidi, M., "System-of-Systems Engineering - A Definition," IEEE SMC 2005, 10-12 Oct. 2005

VA Research Innovation Context

Leading Publications Fields with > 1,000 research publications from 2014-2017:

- Electrical/Electronic Engineering – 4,304 research publications 2014-2017, 1.16 specialization index
- Applied Physics – 1,657 research publications 2014-2017, 0.90 specialization index
- Materials Science – 1,633 research publications 2014-2017, 0.76 specialization index
- Optics – 1,449 research publications 2014-2017, 1.05 specialization index
- Mechanical Engineering – 1,144 research publications 2014-2017, 1.26 specialization index
- Meteorology/Atmospheric Sciences – 1,120 research publications 2014-2017, 1.81 specialization index

Additional areas with significant publications activity include Civil Engineering, Physical Chemistry, Energy/Fuels, Nanoscience/Nanotechnology, Aerospace Engineering, Instrumentation, Nuclear Physics, Environmental Engineering, Transportation Science, and Remote Sensing.

Themes in Major Grants Activity in Relevant R&D Areas:

- Establishment of several IUCRC sites involving unmanned aerial systems and transportation systems testing
- Collaborative research in space weather and atmospheric sensing

Presence of Major Research Centers/Assets:

- NASA Langley Research Center
- VA Space Mid-Atlantic Regional Spaceport
- DoD R&D Intramural and FFRDCs
- Jefferson Labs
- UVA: Commonwealth Center for Advanced Manufacturing (CCAM), Commonwealth Center for Aerospace Propulsion Systems (CCAPS), Institute for Nanoscale and Quantum Scientific and Technological Advanced Research (NanoSTAR), Multi-Functional Integrated System Technology (MIST) Center, UVA Applied Research Institute; Link Lab
- VA Tech: Institute for Critical Technology and Applied Science (ICTAS), Virginia Center for Autonomous Systems, Virginia Tech Transportation Institute, Center for High Performance Manufacturing (CHPM), Center for Power Electronics Systems (CPES)
- GMU: Center for Earth Observing and Space Research (CEOSR), Center for Geospatial Intelligence, Center for Excellence in Command, Control, Communications, Computing and Intelligence (C4I), Center for Spatial Information Science and Systems (CSISS)
- ODU: Virginia Modeling, Analysis & Simulation Center, National Center for System of Systems Engineering (NCSOSE)
- Hampton: Virtual Parts Engineering/Modeling and Simulation (VPMAS)

VA Industry Innovation Context

Leading Patenting Areas with > 100 patent records from 2014-2017:

- No leading areas, some presence of technology areas associated with navigational systems, optical components, and electronics

Leading Venture Capital Investment Areas with > $10 million invested from 2009-2016:

- Electronics and semiconductors: $127.96 million total equity invested 2009-2016
- Industrial equipment: $12.3 million total equity invested 2009-2016

Themes in SBIR Awards Activity in Relevant R&D Areas:

- Sonar, acoustic, and other ocean/naval sensing technologies
- High performance antennas, radars, lidars, and other integrated optics and sensing units
- Propulsion systems and materials for aerospace platforms
- Unmanned aerial vehicles and associated command and control hardware
- High performance electronics components for integration into defense and space systems

VA Supporting Industry Base Context

Significant industries which support and are end users of innovation in this growth area include:

- Engineering Services – 43,897 employees, 1.83 LQ, -14% growth 2009-2016
- Ship Building and Repairing – 23,639 employees, 9.54 LQ, 1.6% growth 2009-2016
- Electric Power Distribution - 5,144 employees, 0.97 LQ, 4.2% growth 2009-2016
- Heavy Duty Truck Manufacturing - 2,930 employees, 4.14 LQ, 70.5% growth 2009-2016
- Search, Detection, and Navigation Instruments - 2,930 employees, 0.83 LQ, -25% growth 2009-2016

Market Potential and Leading Applications

SoSE applications touch a wide-ranging set of markets, giving the area a large overall market size and varying growth prospects depending on applications vertical. Several examples include:

- Global market in integrated sensor systems technology:
  - Automotive industry applications valued at $32 billion in 2017 with CAGR of 11.4%
  - Process industry applications valued at $23.9 billion in 2017 with CAGR of 11.2%
  - Machinery manufacturing applications valued at $12.9 billion in 2017 with CAGR of 11.5%
  - Aircraft and shipbuilding applications valued at $8.5 billion in 2017 with CAGR of 11.3%
- North American market in unmanned systems technology:
  - Unmanned aerial vehicle systems market valued at $155.9 million in 2015 with CAGR of 9.5%
  - Unmanned ground vehicle systems market valued at $53.9 million in 2015 with CAGR of 13%
  - Unmanned marine vehicle systems market valued at $34.6 million in 2015 with CAGR of 12.5%
- Global market in remote sensing platforms:
  - Disaster management applications valued at $2.3 billion in 2016 with CAGR of 11.3%
  - Climate research applications valued at $2.3 billion in 2017 with CAGR of 9.4%

  - Infrastructure applications valued at $1.8 billion in 2017 with CAGR of 6.6%
  - Security applications valued at $1 billion in 2017 with CAGR of 5.3%
  - Oceanography applications valued at $480 million in 2016 with CAGR of 11.5%
  - Energy applications valued at $321 million in 2016 with CAGR of 3.7%
- North American market for intelligent transportation system technologies:
  - Safety and risk management systems market valued at $7 billion in 2014 with CAGR of 16%
  - Vehicle telematics systems market valued at $3.4 billion in 2017 with CAGR of 10.2%
  - Fleet management and asset monitoring systems market valued at $1.8 billion in 2017 with CAGR of 17.1%
- North American market for smart grid-enabling power electronics components valued at $1.3 billion in 2013 with CAGR of 16.5%

Some examples of likely market applications aligned with Virginia's research and innovation strengths include:

- Embedded imaging and geospatial sensing systems
  - Unmanned system sensors and command and control devices
  - Remote sensing networks for environmental and defense applications
- Intelligent transportation systems and vehicle automation
- Networked power electronics systems
  - Networked hardware components and management systems for naval and aerospace vehicles
  - Distributed controllers for smart grid management
- Engineered materials and digital design for SoSE applications

Key Challenges for Virginia's Innovation Ecosystem

Virginia has a set of world class engineering research and innovation assets, but has not yet successfully integrated them together comprehensively to leverage economies of scale for the state. Key challenges to achieving this alignment that were identified from interviews with research and industry stakeholders include:

- The current environment of distributed innovation assets both across many different specific applications verticals and geographically has made growing critical mass locally difficult
- Lack of broader network of industry firms focused on enabling platforms of autonomous systems and sensors that support end-use market products within the state and resulting "export" of innovation to other regions of the country
- Lower emphasis for engineering departments in creating value-driven technology outflows from key university engineering research centers given the high amount of research spending
- Ongoing competitive pressure to relocate key industry and applied R&D operations to other regions of the country that have more integrated ecosystems and supporting clusters of talent and industry operations required for growth
- Migration of young engineering talent away from existing R&D assets that more geographically isolated within the state due to lack of modern urban amenities
- Regulatory and national security issues (such as requirement for security clearances and secure infrastructure) that can hamper growth of business operations

Potential Development Pathways for Virginia Growth

- The key challenge in bringing Virginia to national prominence as an applied systems engineering destination for industry is achieving critical mass around specialized centers of excellence in focused innovation applications. To sustain growth, there is a need to integrate engineering research and development activities in Virginia under the branding identity of system of systems engineering with recognition that this more focused direction supports key verticals within the state such as space, transportation, manufacturing, unmanned systems, and remote sensing. Implement the formation of a research asset consortium to tie together signature institutions and labs in various regions of the state under this common direction and focus research efforts where possible on applied design, testing, and integration applications rather than upstream basic science.
- Establishment of a University Affiliated Research Center (UARC) by the Department of Defense is often a key vehicle for universities to maintain long term strategic partnerships with government sponsors and effectively commercialize applied research. Explore the potential for establishing a UARC at a key Virginia engineering university and conduct any necessary strategic planning exercises to help enable a more robust research commercialization enterprise.
- Key engineering industries often consider the costs of new infrastructure in making strategic growth or relocation decisions. Develop an industry attraction fund that has a broad, flexible framework for awarding resources to help offset the costs of new infrastructure targeted strategically at SoSE companies committed to growing operations within the state around key research facilities.
- Explore the potential for public-private partnerships for development and implementation of additional shared use industry-university applied research centers in key SoSE verticals to serve as regional research activity aggregators utilizing governance and collaboration models similar to Commonwealth Center for Advanced Manufacturing (CCAM). Potential focus areas for new facilities could include unmanned systems, transportation systems, or integrated power electronics.
- Explore development of high profile, state-funded "grand challenge" competitions in several key SoSE applications areas (potentially alongside federal government partners) similar to past DARPA grand challenge models with goal of raising the visibility of state's engineering ecosystem
- Consider restructuring incentives within university engineering faculty tenure systems that encourage increased levels of commercialization of applied research and formation of faculty-led startups
- Develop incentive programs for young talent with skill sets in high demand for SoSE companies and research institutions to help address quality of life and amenities concerns around more regionally isolated SoSE research and industry operations outside of northern VA

IV. Life Sciences

What Is It?

Growth opportunities in this space fall into a broad spectrum of interdisciplinary technologies focused around biology, biotechnology, and medicine. An advanced innovation ecosystem supporting these areas takes promising innovations developed from basic research in biological science and then can quickly translate them into medical or other biotech product and service applications. Integrated bench to market processes will increasingly play a key role in advancing a broad spectrum of new market technologies in life sciences and rely on a well-functioning clinical research environment centered around academic medical centers to enable drug development and clinical trials as well as a well-supported entrepreneurial environment for emerging biotechnology companies.

Endpoint markets for innovations in advanced life science can include:

- Biopharmaceuticals tailored to specific genetic and metabolic biomarkers for treatment of disease
- Advanced diagnostic and testing technologies enabled by genetic sequencing, high throughput sample processing, advanced medical imaging, and novel testing materials development
- Medical devices, particularly those used in diagnostic sensing for clinical care and regenerative medicine focused on biocompatible and implantable materials
- Bioinformatics involving the integration of big data processing and predictive modeling for use in computational biology and healthcare applications
- Commercial and industrial biotechnologies for use in industrial, agricultural, and other bioprocess engineering applications

Virginia's diversity of biomedical and biotechnology innovation assets and the emerging nature of the state's industry ecosystem in this area means that it is important to keep a broader perspective in supporting innovative advancements over time as more distinct areas of specialization develop and mature. Several key areas of innovation developing today revolve around the use of integrated diagnostic and drug development technologies to advance personalized medicine, regenerative medical devices, neurosciences and life science manufacturing.

VA Research Innovation Context

Leading Publications Fields with > 1,000 research publications from 2014-2017:

- Surgery – 1,638 research publications 2014-2017, 1.02 specialization index
- Biochemistry/Molecular Biology – 1,479 research publications 2014-2017, 0.71 specialization index
- Neurosciences – 1,460 research publications 2014-2017, 0.78 specialization index
- Oncology – 1,263 research publications 2014-2017, 0.7 specialization index
- Clinical Neurology – 1,250 research publications 2014-2017, 0.97 specialization index
- Pharmacology/Pharmacy – 1,044 research publications 2014-2017, 0.81 specialization index

Additional areas with significant publications activity include Cellular Biology, Genetics, Radiology/Nuclear Medicine, Cardiovascular Systems, Internal Medicine, Immunology, Health Care Services Science, Microbiology, Endocrinology, Applied Biotechnology, Orthopedics, Infectious Disease, and Gastroenterology.

Themes in Major Grants Activity in Relevant R&D Areas:

- Oncology -- NIH supported Cancer Centers at UVA and VCU
- Immunology, Infectious Diseases and Virology -- USAID grant on HIV to EVMS
- Neurological Sciences -- NIH Program Project Grant in Regulation of Neurotransmitters at UVA
- Orthopedic & Musculoskeletal Disorders -- NSF grant of over $1 million on biomechatronic interface at George Mason Univ.
- Substance Abuse & Mental Illness -- NIH funded Center on Drug Abuse Research at VCU
- Health Care Research – Major grant from Agency for Healthcare Research and Quality on primary care outcomes to VCU
- Genomic Analysis – Major NSF grant to Virginia Tech's Molecular Science Software Institute
- Respiratory Disorders & Conditions -- NIH funded Center for Study of Tobacco Products at VCU
- Molecular and Cellular Biology -- NIH Program Project Grant on role glycosaminoglycans at VCU and NIH Program Project Grant on regulation of vascular physiology and inflammation in tissues at UVA
- Reproductive Biology -- NIH Center of Excellence and Program Project Grant on preterm birth at VCU
- Obstetrics & Gynecology -- NIH Program Project Grant in studies of polycystic ovarian syndrome at UVA

Presence of Major Research Centers/Assets:

- VCU: Massey Cancer Center, Pauley Heart Center, Harold F. Young Neurosurgical Center, VCU School of Medicine Centers and Cores; Medicines for All Initiative
- UVA: UVA Cancer Center, Bernie B Carter Center for Immunology Research, Paul Mellon Prostate Cancer Research Institute, Robert M. Berne Cardiovascular Research Center, BIG-Center for Brain Immunology & Glia, Keck Center for Cellular Imaging, Myles H. Thaler Center for AIDS & Human Retrovirus Research, Global Infectious Diseases Institute, UVA Brain Institute, UVA Data Science Institute; Center for Applied Biomechanics
- VA Tech: Virginia Tech Carilion Research Institute, Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences
- GMU: Center, Applied Proteomics and Molecular Medicine (CAPMM), National Center for Biodefense and Infectious Diseases, Center for Biomedical Genomics (CBMG), MicroBiome Analysis Center (MBAC)

VA Industry Innovation Context

Leading Patenting Areas with > 100 patent records from 2014-2017:

- Surgical devices – 263 patent records, 0.77 specialization index, 1.04 forward citation impact index
- Biopharmaceuticals – 245 patent records, 0.70 specialization index, 0.70 forward citation impact index
- Biological materials/substances analysis technologies – 215 patent records, 0.81 specialization index, 0.60 forward citation impact index

- Diagnostic sensing medical devices – 196 patent records, 0.55 specialization index, 0.56 forward citation impact index
- Medical prosthetics and filters – 155 patent records, 0.62 specialization index, 0.64 forward citation impact index
- Measuring or testing processes involving enzymes or micro-organisms – 111 patent records, 0.53 specialization index, 0.55 forward citation impact index

Leading Venture Capital Investment Areas with > $10 million invested from 2009-2016:

- Medical/Health Services: $523.4 million total equity invested 2009-2016
- Medical/Health Products: $63.4 million total equity invested 2009-2016
- Biotech Research: $60.9 million total equity invested 2009-2016
- Pharmaceuticals: $18.7 million total equity invested 2009-2016

Themes in SBIR Awards Activity in Relevant R&D Areas:

- Development of drug discovery targets and biomarkers
- Medical nanoparticles for imaging and drug delivery
- Remote health monitoring and web-based health IT software solutions

VA Supporting Industry Base Context

Significant industries which support and are end users of innovation in this growth area include:

- Medical and Surgical Hospitals – 97,428 employees, 0.83 LQ, -1% growth 2009-2016
- Medical Laboratories – 6,620 employees, 1.33 LQ, 27% growth 2009-2016
- Blood and Organ Banks - 2,415 employees, 1.39 LQ, 15% growth 2009-2016

Market Potential and Leading Applications

Life sciences markets encompass a broad set of opportunities, many of which have high market sizes and promising growth prospects. Some examples of likely market applications aligned with Virginia's research and innovation strengths include:

- Neuroscience diagnostics and sensing, a global market of over $24 billion linked strongly to on ongoing brain mapping research and investigation projects aimed to better understand complex neuronal circuits, nervous functioning, and neuronal manipulation. Plus, neurological disorders, comprising more than 600 conditions that affect the nervous system, impact an estimated 50 million Americans every year and is a major area of new therapeutic development according to PhRMA, with 420 drugs in development for neurological disorders, including well-known diseases such as epilepsy, traumatic brain injury, multiple sclerosis, Parkinson's disease and Alzheimer's disease.
- Personalized medicine solutions, with noninvasive and companion diagnostics development valued at $4.3 billion in 2016 with CAGR of 32.3%
- Regenerative medicine solutions with substantial existing markets, including joint implant and regenerative products market valued at $30.1 billion in 2014 with CAGR of 2.7%; bone repair and regenerative products

market valued at $4.4 billion in 2014 with CAGR of 3.8%; and cartilage and soft tissue repair and regenerative products market valued at $1.8 billion in 2014 with CAGR of 6.6%

- Healthcare analytics solutions, a fast-growing though not yet large market, including: quality improvement and clinical benchmarking systems market valued at $280 million in 2017 with CAGR of 18.2%; clinical decision support systems market valued at $485 million in 2017 with CAGR of 17.5%; comparative analytics and comparative effectiveness systems market valued at $206 million with CAGR of 16.7%; medical claims and financial analytics systems market valued at $1.5 billion in 2017 with CAGR of 11.9%
- Addiction therapies valued as a $35 billion market in 2015 with projected annual growth of 5%
- Cancer therapeutics market that reached $121 billion in 2017 and should reach $172.6 billion by 2022, a compound annual growth rate (CAGR) of 7.4% from 2017 to 2022.

Key Challenges for Virginia's Innovation Ecosystem

Virginia's life sciences ecosystem is still emerging and a result faces growth and coordination challenges as it matures to scale. Several of these challenges that were identified from interviews with research and industry stakeholders include:

- Lack of commercial wet lab space in some areas of the state where where biosciences start-ups are taking root. The lack of significant public-private partnerships for biotech infrastructure amplifies this issue as a pain point for emerging companies.
- Lack of critical mass in bioscience talent needed to grow emerging companies and applied R&D. As a result, a number of companies tend to migrate to adjacent regions with stronger bioscience industry clusters in Maryland and North Carolina to tap into their talent base.
- Observation that relatively few companies are leveraging small business grant and funding resources like the SBIR program
- Many large bioscience companies that have achieved success and reached maturity in Virginia operate in niche markets that don't easily connect with a wider community to foster an integrated ecosystem
- Lack of external funding resources from either VC, state, or industry partner sources for businesses to scale up research and clinical trials activities in therapeutics applications areas. Given limited options, companies tend to turn to out of state funding that ultimately puts pressure on them to move operations closer to funding sources.

Potential Development Pathways for Virginia Growth

- Life sciences cluster development calls for especially close ties between industry, clinical care and academic R&D. In Virginia, life sciences is still an emerging industry that needs to draw upon the capabilities of the state's research institutions and growing interest in innovation and collaborations with academic hospitals through increased coordination with flexibility to develop a more distinct identity over time.
- Life sciences is an active area of university technology commercialization and industry partnerships in Virginia. Most university start-ups are found in life sciences applications (50+ companies in past 5 years) and this ecosystem could be greatly enhanced by further use of proof-of-concept funding and milestone-driven translational research resources. There is also significant licensing activity and significant partnerships with major life sciences companies that can be leveraged to develop strategic partnerships over time.

- Virginia is strategically located between two major industry centers of life sciences – North Carolina and Maryland – and can take advantage by creating a value proposition around key collaborative and signature strengths that complement those regions rather than compete with them. Some examples include:
    - Neuroscience Initiative creating a significant translational/clinical research value proposition with statewide clinical trials network and patient registry – next stages could include building up biobanking and signature shared use laboratories
    - Biomanufacturing may be another key opportunity through leveraging VCU's Medicine for All initiative that is revolutionizing manufacturing of small chemical drugs as well as UVA's Laboratory of Regenerative Therapeutics that has GMP capacity for innovative cell and tissue therapies
- Even though life sciences represents 49% of university research in Virginia, or nearly $700 million annually, there is still considerable investment needed to be competitive. Virginia universities have only a handful of major NIH-funded research centers, and significant funding to foster emerging areas of innovative specialization are required to accelerate growth. Potential ways to help structure ongoing investment can include:
    - Develop a statewide approach to build "collaborative" strength using existing initiatives in neurosciences and genomic-based medicine as a potential model for the future. As a part of this approach, there is a critical need to further develop a mechanism for leveraging Virginia's major hospital systems as a key component of a collaborative environment
    - Conduct thorough assessments for targeted investments to guide all of Virginia's life sciences initiatives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