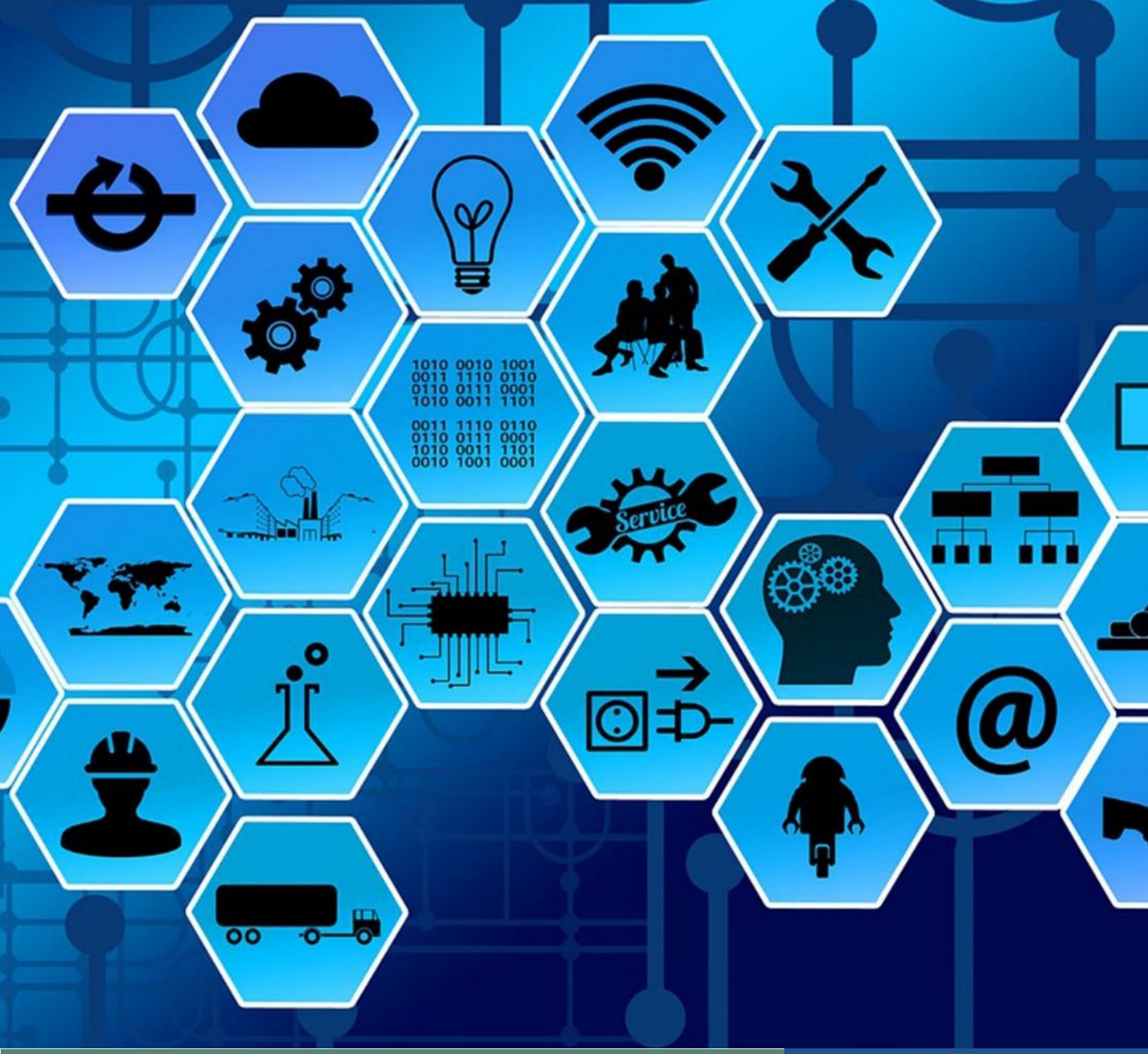


Commonwealth Research and Technology Strategic Roadmap

October 16, 2019

STATE COUNCIL OF HIGHER EDUCATION FOR VIRGINIA

VIRGINIA RESEARCH INVESTMENT COMMITTEE

CONTENTS

EXECUTIVE SUMMARY

The Commonwealth Research and Technology Strategic Roadmap, created in statute, identifies research areas worthy of economic development and institutional focus. The process employed for the 2019 Roadmap included development of the primary document by the State Council of Higher Education for Virginia (SCHEV), review and approval by the Virginia Research Investment Committee (VRIC) and final approval by the Governor. The areas of research focus identified through this new Roadmap-development process as exhibiting the most worth and promise for Virginia's economic growth are:

1. **Life and health sciences;**
2. **Autonomous systems;**
3. **Space and satellites;**
4. **Agricultural and environmental technologies;**
5. **Cybersecurity; and**
6. **Data science and analytics.**

Knowledge, innovation and collaboration drive economic growth. Virginia's strongest asset for such growth is the collective expertise of its institutions of higher education and private sector industries. The new Roadmap also offers a comprehensive and cohesive framework to foster collaboration between higher education, economic development and private sector industry along the continuum from research to commercialization.

Five core categories of options for collaboration form the framework for fulfilling this statutory goal:

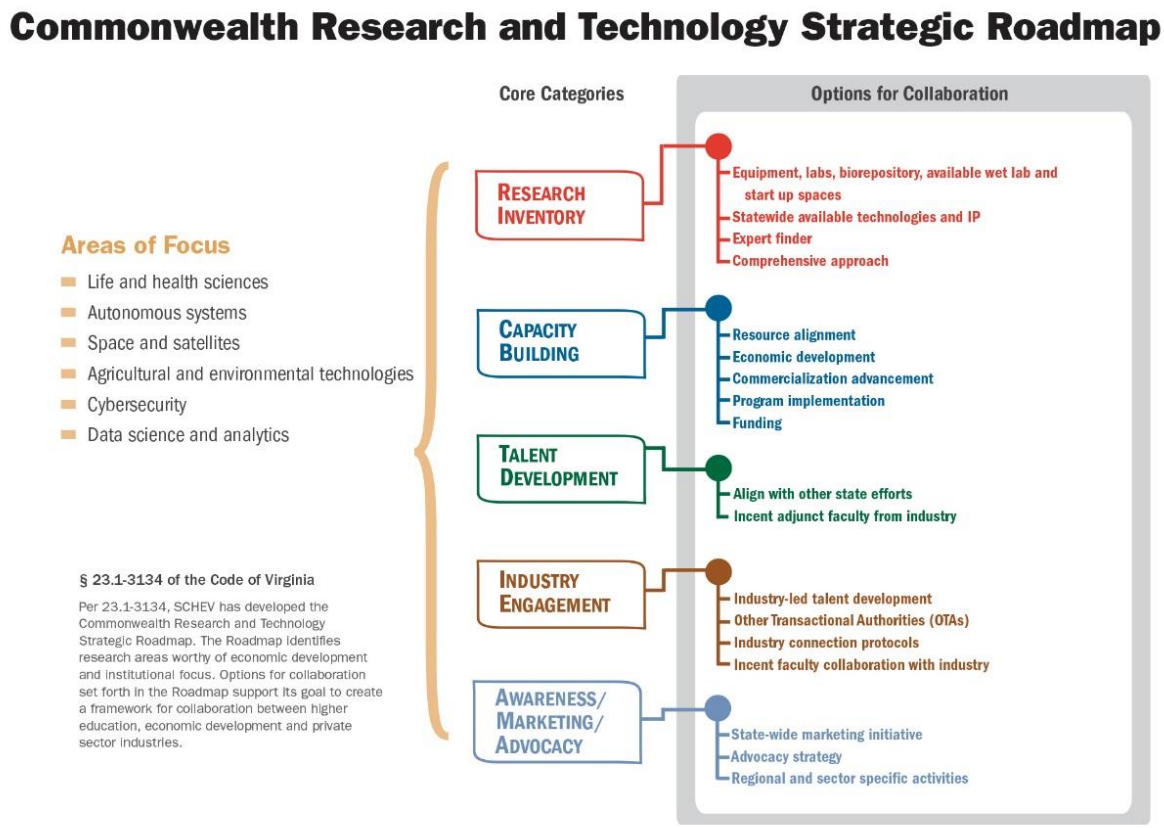
1. **Research inventory;**
2. **Capacity building;**
3. **Talent development;**
4. **Industry engagement; and**
5. **Awareness/marketing/advocacy.**

The Roadmap development process included consultation by SCHEV and VRIC with a panel of independent experts to produce the Roadmap, gathering qualitative input from an array of stakeholders and quantitative input from various data sources. Analysis of

that input - along with higher-education research priorities, supporting public, private and federal assets and target industry sectors - revealed common themes that determined the focus areas identified in the new Roadmap.

As a group, the panel of independent experts viewed the six focus areas as either "vertical" areas (four) or "horizontal" areas (two). The vertical focus areas - life and health sciences; autonomous systems; space and satellites; and agricultural and environmental technologies - have specific end users and include sub-vertical priority areas. The horizontal focus areas - cybersecurity; and data science and analytics - cut across many different industry sectors. Therefore, the two horizontal areas have no priority areas and are intentionally broad.

Stakeholder input generated the options recommended here to achieve the Roadmap's goal of developing a framework for collaboration spanning from research to commercialization. Research and data analysis validated inclusion of the five core categories of options for collaboration. The visual roadmap below depicts these aspects.



Stakeholders also stressed the importance of measuring progress in these areas. The detailed Roadmap narrative outlines potential metrics to do so.

The intended outcome of the strategic Roadmap is to best position the Commonwealth and its resources to grow Virginia's economy at large by growing its innovation economy. The Roadmap narrative and appendices A, B, C, and D lay out the path to achieve this outcome.

INTRODUCTION

The Commonwealth Research and Technology Strategic Roadmap (The Roadmap) is a coordinated and concerted statutory effort to fortify Virginia's economy through strategic actions and collaboration. The roadmap identifies and focuses collaboration around sectors that offer the most promise for growing Virginia's innovation economy.

Specific areas of opportunity within Virginia's innovation economy include life and health sciences; autonomous systems; space and satellites; agricultural and environmental technologies; cybersecurity and data science and analytics as identified in the Commonwealth Research and Technology Strategic Roadmap.

This document outlines the statutory process, areas of focus and options for collaboration to support collaborative research, development and commercialization efforts around those areas of focus. Several appendices supplement the Roadmap narrative offering various data points and inputs that support the recommendations herein the Roadmap.

SUMMARY OF THE ROADMAP DEVELOPMENT PROCESS

The process by which SCHEV developed the Roadmap is both cohesive and comprehensive. The process began with the identification and assemblage of a panel of independent experts to consult on areas of research focus and common themes. The experts were individuals from across the Commonwealth with deep knowledge in specific sectors and diverse expertise in research, development and commercialization activities. Panel representation included higher education, economic development, the private sector, and federal research entities.

The thirteen-member panel convened twice to discuss common themes that emerged from SCHEV's research, analysis and stakeholder input regarding research areas of focus and options to achieve the roadmap's goal: "to develop a framework through which to encourage collaboration" between higher education, economic development and the private sector in the Commonwealth. (Source: 23.1-3134)

The resulting roadmap blends findings from quantitative data sources and qualitative feedback on emerging opportunities. Below is a sampling of some of the stakeholders from whom SCHEV solicited qualitative input:

- The Virginia Research Investment Committee (VRIC);
- The State Council of Higher Education for Virginia (SCHEV Council);
- Public and private institutions of higher education in the Commonwealth;
- Individual members of the National Academies of Sciences, Engineering and Medicine;
- Individual members of the Virginia Academy of Science, Engineering and Medicine;
- Federal research and development assets in the Commonwealth;
- Regional Technology Councils in the Commonwealth;
- Individual members of the Research and Technology Investment Advisory Committee;
- Selected staff of the Virginia Economic Development Partnership;
- Chairs of the House Appropriations Committee and Senate Finance Committee;
- The Joint Commission on Technology and Science; and
- The private sector.

Through its Roadmap development process, SCHEV also fulfilled statutory mandates to include appropriate review by the SCHEV Council and formal approval by VRIC. Appendix A includes a detailed account of the Roadmap development process and timeline. Appendix B provides detailed data pertaining to the Commonwealth's innovation economy.

DETAILED ROADMAP NARRATIVE

Research Areas Worthy of Focus

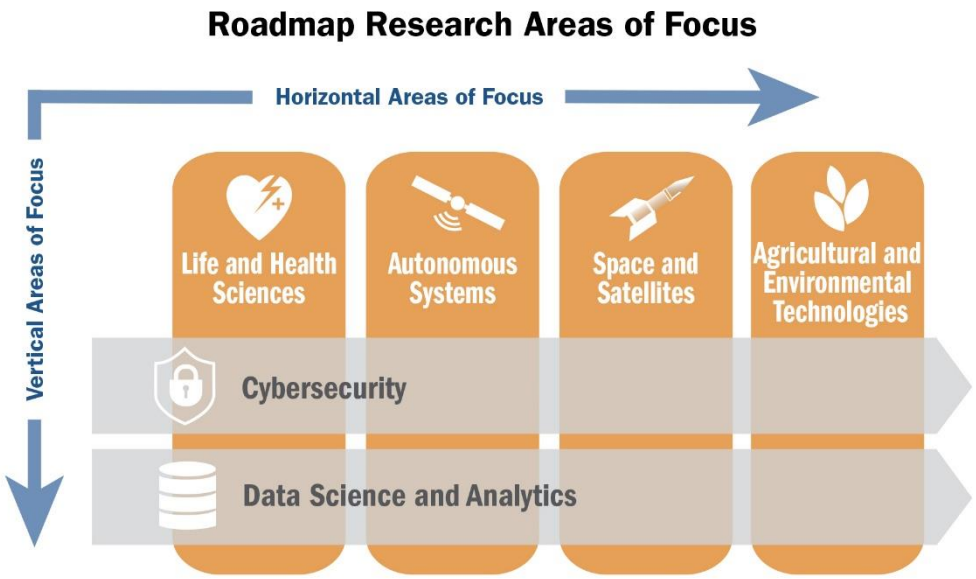
An analysis of both quantitative and qualitative inputs determined the areas of focus. Quantitative input includes data collected by SCHEV and previous (2017) research performed by TEConomy Partners, a consultant hired by SCHEV on behalf of VRIC, which assessed the Commonwealth's research and innovation assets. Other state-based data sources include GO Virginia, the Virginia Economic Development Partnership (VEDP) and research priority lists from Virginia's public institutions.

Through analysis of this data in conjunction with stakeholder and expert panel input, common themes emerged. A critical mass of assets or a leading edge towards emerging opportunities along with data points supporting tangible market opportunities and frequency of stakeholder input led to six research areas worthy of Roadmap focus:

1. **Life and health sciences;**
2. **Autonomous systems;**
3. **Space and satellites;**
4. **Agricultural and environmental technologies;**
5. **Cybersecurity; and**
6. **Data science and analytics.**

The consensus of the panel of independent experts was that the six areas of focus all warrant attention, strategic efforts and further investment. The first four represent vertical market opportunities each with a subset of priority areas (priority sub-verticals). The last two, cybersecurity and data science and analytics, represent crosscutting horizontal markets that support the first four along with other verticals that are not areas of focus. As horizontal areas of focus, these two are intentionally broad with no subset of priority areas.

A detailed description of each area of focus appears below and includes a definition, explanation of priority areas where applicable and several data points to support inclusion. For an in-depth analysis of each area of focus, please refer to Appendix C.



Verticals – These vertical areas of focus are defined as such because they offer products/technologies and innovation for a specific customer and industry base. Each vertical area of focus includes priority sub-verticals based on research, commercialization and other assets. Priority areas are just that - priorities where real opportunity exists for Virginia to compete successfully.

Those sub-verticals should receive priority for Virginia Research Investment Fund (VRIF) and Commonwealth Research Commercialization Fund (CRCF) support. However, narrowing the innovation funnel too much at the onset will result in even more narrow outcomes. Language stating, "not limited to" allows other requests within each area of focus to be considered when warranted.

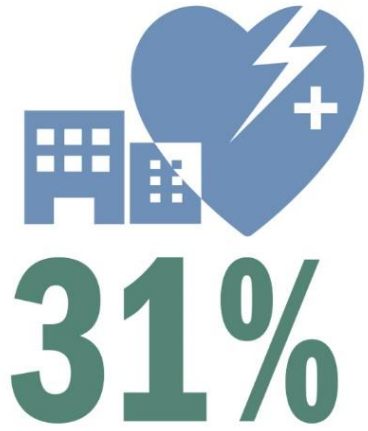
1. Life and health sciences - The Commonwealth Research and Technology Strategic Roadmap calls upon the following prioritized sub-verticals in life science and health related fields (but not limited to):

a. **Neuroscience research, advanced technologies and regulated products.**
b. **Biomedical informatics.**
c. **Medical and surgical devices.**
d. **Advanced biopharmaceutical manufacturing.**
e. **Synthetic biology – an emerging, interdisciplinary priority area applying engineering principles to biology to redesign and fabricate new biological components and systems.**

The majority of stakeholder input indicated that this area of focus is quite, if not overly, broad and is in need of priority areas of further focus. Data reinforces that the Commonwealth has significant research, development and commercialization activity within this area, but critical mass must be cultivated around specific sub-areas where Virginia has substantial opportunity. Priority areas 1a-e above represent those areas.

The following list highlights key opportunities and activities in Virginia's Life and Health Sciences area of focus.

- Neuroscience as a priority sub-area aligns with and supports the Virginia Catalyst's Neuroscience Initiative and research activities underway across Virginia by a core of eminent researchers across the state.
- In 2019, the University of Virginia received $120M from a private investor to create the School of Data Science. This school is an outgrowth from work done by Dr. Phil Bourne and the Data Science Institute. Many other higher education institutions in Virginia are developing data science programs to meet student and employer demand.
- In 2018, Stryker acquired Virginia-based spine surgical device company, K2M, for $1.4 billion. Stryker is one of the world's leading medical technology companies.
- From 2014-2016, Virginia saw an increase by 37% in new biopharmaceutical companies. (Source: Virginia Bio)



Source: Virginia Bio

Life Science Research & Development Assets

1 Virginia Tech Corporate Research Center
2 Fralin Biomedical Research Institute at VTC
3 Institute for Advanced Learning and Research
4 SRI Shenandoah Valley
5 Integrated Translational Health Research Institute of Virginia (iTHRIV)
6 UVA Cancer Center
7 University of Virginia Research Park
8 INNOVATION @ Prince William
9 American Type Culture Collection (ATCC)
10 George Mason University National Center for Biodefense and Infectious Diseases
11 Howard Hughes Medical Institute, Janelia Research Campus
12 Inova Center for Personalized Health (including Inova Schar Cancer Institute & Inova Translational Medicine Institute)
13 National Institute of Standards and Technology (NIST)
14 National Institutes of Health (NIH)
15 Food and Drug Administration (FDA)
16 Defense Health Agency
17 Defense Advanced Research Projects Agency (DARPA)
18 National Science Foundation (NSF)
19 U.S. Patent and Trademark Office
20 Virginia Division of Consolidated Laboratory Services (DCLS)
21 Medicines For All Institute at VCU
22 Hunter Holmes McGuire VA Medical Center
23 Virginia Bio+Tech Park
24 VCU Massey Cancer Center
25 VCU Wright Center for Clinical and Translational Research
26 Commonwealth Center for Advanced Manufacturing
27 Virginia Institute of Marine Science
28 Tech Center Research Park
29 Thomas Jefferson National Accelerator Facility
30 Hampton University Proton Therapy Institute
31 NASA Langley Research Center
32 Innovation Research Park @ ODU
33 ODU Frank Reidy Research Center for Bioelectrics
34 LifeNet Health Institute of Regenerative Medicine
35 VABeachBio Research Park

Source: VEDP.org

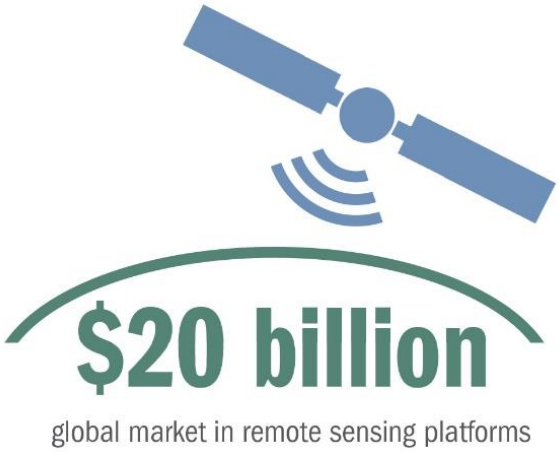
2. Autonomous systems -The Commonwealth Research and Technology Strategic Roadmap calls upon the following prioritized sub-verticals in autonomous systems (but not limited to):

a. **Teaming - Coordination and interoperability between land, air and seafaring autonomous vehicles.**
b. **Remote sensing - For example, antennas, radars, lidars, integrated optics.**
c. **Command and control - For example, hardware and decentralized capabilities as related to the defense sector.**
d. **Urban air mobility - Opportunities relative to current technology testbed activities by NASA Langley.**
e. **Communication protocols (5G and others) - Integration with next generation cellular networks for remote access and control of various autonomous systems.**

Autonomous systems as an area of focus includes unmanned air, land and sea vehicles and also broader capabilities relative to smart technology, smart cities and next generation (5G) cellular network technology. A subset of common themes within this sector emerged through research and stakeholder engagement identified above as priority areas.

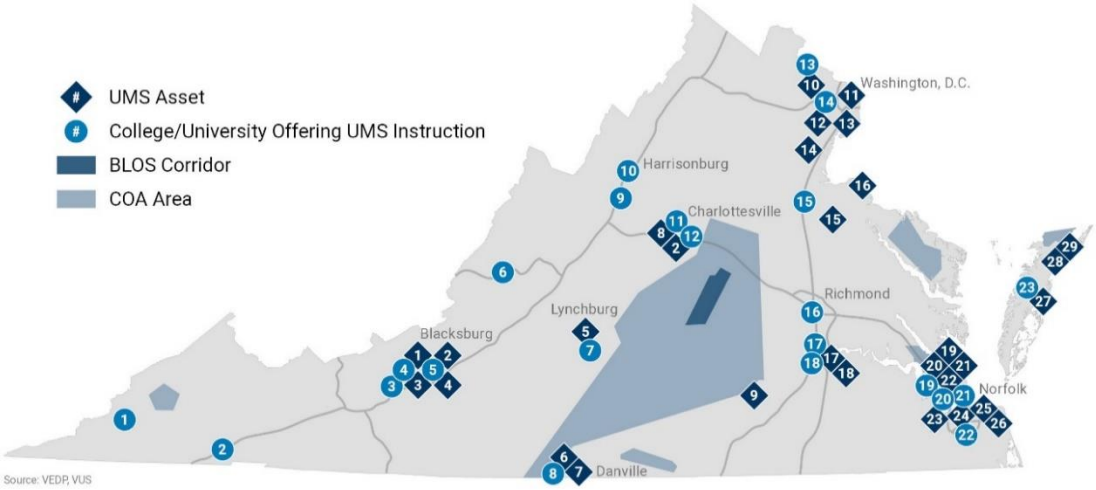
The following examples highlight key opportunities and assets in Virginia's Autonomous Systems area of focus.

- Proximity of Port of Virginia, NASA Wallops Flight facility, various branches of the armed forces allows for teaming and testing of interoperability, communication and command and control between land, air and sea autonomous vehicles.
- Supporting Small Business Innovation Research (SBIR) Award activity in relevant research and development areas.
- Significant supporting industries with emerging autonomous systems technology development: Virginia's largest private employer, Huntington Ingalls Newport News Shipbuilding and Volvo.



Source: TEConomy Partners Line of Sight Analysis

- Majority acquisition of unmanned autonomous vehicle start up, Torc Robotics (a Virginia Tech spin out), by Daimler in 2019.
- Research work at the Commonwealth Center for Advanced Manufacturing focusing on autonomous robotics, advanced sensing and other research around "smart factories."



UMS Assets

1 Mid-Atlantic Aviation Partnership
2 Commonwealth Center for Aerospace Propulsion Systems*
3 Virginia Tech Transportation Institute
4 Virginia Automated Corridor: Virginia Smart Road
5 Center for Advanced Engineering & Research (CAER)
6 Institute for Advanced Learning and Research
7 Virginia Automated Corridor: Virginia International Raceway
8 National Center for Hypersonic Combined Cycle Propulsion
9 Fort Pickett
10 Virginia Unmanned Systems Center
11 Defense Advanced Research Projects Agency (DARPA)
12 Virginia Automated Corridor: Northern Virginia
13 Fort Belvoir
14 Marine Corps Base Quantico
15 Fort A.P. Hill
16 Naval Surface Warfare Center Dahlgren Division
17 Fort Lee
18 Commonwealth Center for Advanced Manufacturing
19 National Institute of Aerospace
20 Virginia Space Grant Consortium
21 Joint Base Langley-Eustis
22 NASA Langley Research Center
23 Virginia Modeling, Analysis and Simulation Center
24 Naval Station Norfolk
25 Navy's Combatant Craft Division
26 Naval Air Station Oceana
27 VIMS Eastern Shore Laboratory
28 Mid-Atlantic Regional Spaceport
29 NASA Wallops Flight Facility

* Multiple VA locations

Colleges/Universities Offering UMS Instruction

1 Mountain Empire Community College
2 Virginia Highlands Community College
3 New River Community College
4 Radford University
5 Virginia Tech
6 Dabney S. Lancaster Community College
7 Liberty University
8 Danville Community College
9 Blue Ridge Community College
10 James Madison University
11 University of Virginia
12 Piedmont Virginia Community College
13 GWU Virginia Science & Technology Campus
14 George Mason University
15 Germanna Community College
16 Virginia Commonwealth University
17 John Tyler Community College
18 Virginia State University
19 Christopher Newport University
20 Thomas Nelson Community College
21 Hampton University
22 Old Dominion University
23 Eastern Shore Community College

Source: VEDP.org

3. Space and satellites - The Commonwealth Research and Technology Strategic Roadmap calls upon the following prioritized sub-verticals in space and satellites (but not limited to):

a. **Small satellites - Next generation satellites will be smaller and more populous. Coordination of these satellites, respective data stored separately, and collective analysis of data from multiple small satellites.**
b. **Commercial spacecraft.**
c. **Commercial rockets.**
d. **Communication protocols (5G and others) - Satellite communication with next generation cellular networks.**

While space and satellites is a mature industry in Virginia, significant market shifts warrant continued and enhanced investment around research, development and commercialization in this area. Spaceflight and rocket launch barriers to market entry have decreased, and startups are infiltrating the market. The area dominated previously by major industry names now has significant startup activity. This opens up opportunity for further growth in Virginia around its space assets by new and emerging companies.

The following examples highlight key opportunities and assets in Virginia's Space and Satellite area of focus.

- In late 2018, Rocket Labs selected NASA Wallops Flight Facility to locate its second small satellite orbital launch complex.
- Venture capital support for this area of focus is increasing by number of deals funded (including funding of Rocket Labs and other Virginia-based competitors).
- Virginia's Mid-Atlantic Spaceport (MARS) is one of four FAA approved spaceports. (Source: MARS)

Source: VEDP

4. Agricultural and environmental technologies - The Commonwealth Research and Technology Strategic Roadmap calls upon the following prioritized sub-verticals (but not limited to):

a. **Precision agriculture - Crop efficiency.**
b. **Water purification/filtration.**
c. **Biodesigned food sources - For example, biostimulants, microbiome enhancements. Efforts to yield more nutritious and resilient food sources (plant and livestock).**
d. **Sea level rise - Increased sea levels and associated flooding risks resulting from environmental degradation.**

Stakeholder input from across the state and across areas of expertise supported inclusion of agriculture as a standalone sector. Input also included environmental technologies as a related area connected to agriculture by sustainability and resilience. Resilience is a concept focused on preparations for and recovery from a disruptive event, short-term or persistent. Sustainability is a concept with longer-term outcomes focused on a triple bottom line of social, economic and environmental impacts. (Source: ScienceDirect) These two concepts complement each other.

One example of the agricultural and environmental connection in Virginia is its oyster industry. Oysters are natural filter feeders for water, helping filter and purify rivers and waterways from nonpoint source pollution such as fertilizers. Their filtration fosters sustainable impacts on recreation, the economy and environment. Oyster reefs also support resilient shores by mitigating against beach erosion from heavy waves, such as those from hurricanes. (Source: VIMS)

The following list highlights the significant role of this sector in Virginia's economy along with key opportunities for research, development and commercialization.

- As Virginia's largest private sector industry, agriculture includes more than 334,000 jobs in the Commonwealth. Agriculture and forestry products also account for more than half of Virginia's exports by volume. (Source: VDACS)
- Hampton Roads is home to the nation's largest and deepest natural harbor. Associated commercial activity at the Port of Virginia and various military installations (Langley Air Force Base,

Source: VDACS

Norfolk Naval Weapons Station, etc.) along with the location of Virginia's single largest employer, Huntington Ingalls Newport News Shipbuilding, in this area make its resilience paramount to Virginia's economy.

- Development of the Smart Farm network by Virginia Tech deploying use of precision agriculture, autonomous systems, biodesign and other technologies to yield increased crop outputs and efficiency and resilient crops.
- Mahindra Corporation, one of the largest manufacturers of global farm equipment, selected Blacksburg, VA in 2018 for its new research center to develop new farm technology products.
- RISE Resilient Innovations is the result of $120 million grant to the Commonwealth from the Department of Housing and Urban Development's (HUD) 2017 resilience competition for projects in the Hampton Roads region. More than $5 million from this award is earmarked to create a resilience innovation hub in the region - the first of its kind in the nation.

Horizontals - Cybersecurity and data science and analytics are horizontal areas of focus because they offer product and technological innovation across a wide array of customers and markets, including the vertical markets listed above. Qualitative and quantitative inputs support these as individual areas of focus. These two horizontal areas include no priority sub-areas herein. Cultivation of broad research, development and commercialization activities within these horizontals will also support the four vertical areas of focus. For an in-depth analysis of strengths, weaknesses, opportunities and threats by area of focus, please refer to Appendix C.

5. Cybersecurity - Cuts across all vertical sectors of focus.

Cybersecurity is a mature area of focus in Virginia but will continue to be of importance. Virginia has many leading-edge strengths in this area.

- Virginia is home to the highest concentration of cybersecurity jobs across all states, 3.3 times the national concentration level. (Source: TEConomy Partners)
- The Commonwealth Cyber Initiative represents a $25M funded cyber-ecosystem including talent development, research and commercialization and industry collaboration.

Source: VEDP.org and Bureau of Labor Statistics

- The decision by Amazon to locate its East Coast headquarters in Virginia will further build the technology talent pipeline more broadly and compliment growth in this area.
- The 2016 North American market for encryption security technologies as a cyber-subset is valued at $8.7 billion with a compound annual growth rate of more than 13%. (Source: TEConomy Partners)

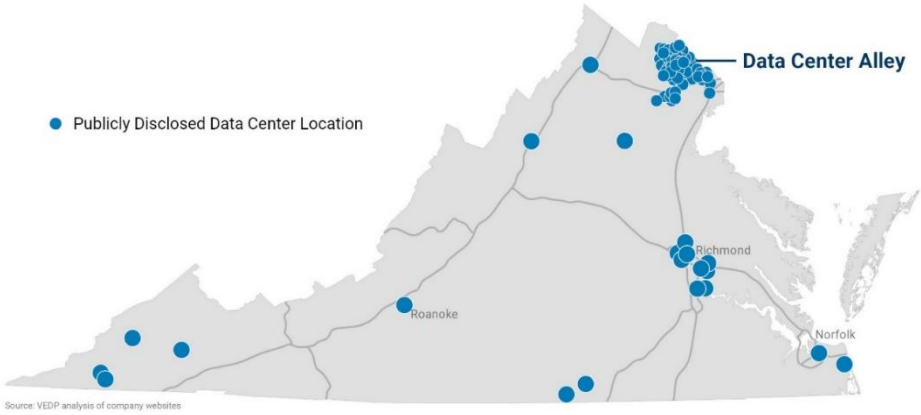
6. Data science and analytics - Cuts across all vertical sectors of focus.

One of the three most resounding inputs was the identification of data as a major area of opportunity for Virginia with unparalleled assets. As a horizontal area of focus, it includes no priority sub-areas herein. Research, development, commercialization and investment in this sector will maintain and grow Virginia's stature.

- Virginia, specifically Northern Virginia, is the global leader of data centers by far. In 2018, Northern Virginia's data center footprint absorbed 270 megawatts (MW) of the global market and led the market for the fifth year in a row. London, the second largest, absorbed 69MW - almost four times less. (Source: Jones Lang LaSalle)
- Since the cultivation of data centers in the 1990s, Northern Virginia has proliferated to offer the highest density of dark fiber (unused fiber optic cable) in the world. This unique asset supports data center growth and unrivaled compute power in Loudoun County/Northern Virginia. (Source: VEDP.org)

Source: Cyberstates 2019, Hoovers and CB Insights

- Virginia ranks 2nd in highest concentration of tech sector employment nationally. (Source: Cyberstates 2019)



Major Data Centers in Virginia

*Multiple VA locations

Amazon Web Services*	DXC Technology	Mineral Gap
ATI	EdgeConneX*	Northrop Grumman*
Atlantic Metro Communications	Equinix*	OnePartner ATAC
Bank of America*	Experis Data Centers*	OVH
Capital One	Facebook	Pixel Factory Data Center
CenturyLink*	Flexential	Quality Technology Services (QTS)*
CloudHQ	Globalinx Data Centers	RagingWire*
Cogent Communications*	H5 Data Centers	Sabey Data Centers
COPT	HopOne Internet Corp.*	TNDSYS (Native Cloud)
CoreSite Real Estate*	Infotel Systems	Vantage Data Centers
CyrusOne LLC*	IPI Data Center Partners Management	Virtustream Inc.
Cyxtera*	Iron Mountain	Zayo Group*
DBT-Data*	MFX	
Digital Realty Trust*	Microsoft Corp.	

Source: VEDP.org

Options for Collaboration

The identification of the six research areas worthy of focus sets the context for achieving the goal of the roadmap - creating a framework to facilitate collaboration between higher education, private sector industry and economic development around those foci. The Roadmap's statutory goal encourages collaboration along the continuum from basic research through to commercialization.

Through the input process, five common themes/core categories for options to facilitate collaboration emerged:

- Research inventory;
- Capacity building;
- Talent development;
- Industry engagement; and
- Awareness/marketing/advocacy.

Research Inventory

The Roadmap statute requires establishment of a research and development inventory. After completion and approval of the Roadmap, and consistent with existing Code requirements, SCHEV will follow a similar process to develop the research inventory. The scope of such an inventory can vary widely. The implementation of an inventory can also inform future roadmaps and areas of focus for the Commonwealth as well as tie into and support the other core categories outlined in this section. More details regarding each option for collaboration are included in Appendix D.

Research Inventory Options for Collaboration
Develop a portal and identify equipment, biorepository, core labs and other assets for sharing/use. Connect with relevant, existing sites and building inventories.
Develop an inventory portal of statewide available technologies and intellectual property (IP).
Explore state purchase and licensing of a research, development and commercialization inventory web-based platform.
Create a comprehensive and cohesive research and development inventory. This would enable identification of faculty by area of focus and research activity along with available IP, shared equipment, clinical trial information and startups.

Capacity Building

The most frequent stakeholder input centered on building the Commonwealth's research, development and commercialization capacity in a variety of ways to yield more cohesive and collaborative results.

Resource Alignment

Alignment of resources was top of mind after the 2019 General Assembly legislative session, which saw three bills aimed to overhaul and streamline resources for research, development and commercialization. The vast majority of stakeholder input supports a more streamlined and coordinated process.

Three iterations of resource alignment input include:

Resource Alignment Options for Collaboration
Concept 1: Aggregating existing programs, funding and associated processes and databases.
Concept 2: Deploying a hub and node model (either centralized or via area of focus).
Concept 3: Implementing new programs addressing stakeholder needs/requests such as proof of concept programs and commercialization advancement plans.

Economic Development

Stakeholders indicated the need for more collaboration with economic development entities to serve as a primary connector between university innovation and industry engagement. The table below outlines these activities. Also, Appendix D: Options for Collaboration outlines the details of each option as well.

Economic Development Options for Collaboration
Develop a process and establish an economic development point of contact for routine review of technology portfolios with technology transfer offices (TTOs) and Chief Research Officers at the public higher education institutions, to inform state-level business development efforts.
Include acquisition assistance to state economic development activities where licensing of technologies developed by faculty could drive existing industry growth or prospect activity through acquisition.
Foster formation of a Mid-Atlantic alliance for research, development and commercialization in aligning areas of focus.
Work with various economic development organizations to leverage opportunity zones, enterprise zones and other designated development areas in the Commonwealth.

Commercialization Advancement

Commercialization advancement measures are integral to build capacity at the institution and statewide levels. Appendix D also outlines further details of each option for collaboration.

Commercialization Advancement Options for Collaboration
Design sector-based technology transfer office (TTO) collaborative agreements among institutions.
Create a statewide industry sponsored research agreement between institutions and industry.
Produce a statewide portfolio of intellectual property (IP) across all universities.
Develop TTO templates/share of best practices/regional staffing agreements where appropriate.
Explore statutory language regarding state funds for patents and patent resource allocation.
Consider changes to state R&D tax credit qualification to increase research and development expenditures and commercialization activities.

Program Implementation

A variety of programs will also build capacity around specific focus areas. Appendix D outlines these in more detail.

Program Implementation Options for Collaboration
Explore opportunities for research centers of excellence.
Create a government-university-industry research roundtable.
Enhance entrepreneurial support at institutions of higher education in the Commonwealth.

Funding

Venture capital funding is another critical component of capacity building. The steps provided below aim to increase funding from the private sector. Refer to Appendix D for more information.

Funding Options for Collaboration
Consider using state funds to match angel funds up to a certain percentage.
Attract a venture capital representative from a prime venture capital location to have a presence in Virginia.
Implement a venture capital “shopping spree” as part of a statewide proof of concept program.
Promote and facilitate regional venture capital connections to address regional mismatch challenges.

Talent Development

Stakeholders expressed the importance of ensuring a talent pipeline to support the growth of the Roadmap's focus areas. Input ranged from steps to take at the community college level to connection with statewide initiatives underway. Appendix D outlines the options for collaboration more specifically.

Talent Development Options for Collaboration
Align with other state-level efforts ranging from community college initiatives to economic development initiatives.
Encourage public institutions to develop industry partnerships to consult on curriculum development and utilize adjunct faculty with current industry experience in those areas of focus to help keep curriculum current.

Industry Engagement

From 2010 to 2015, industry-funded research and development increased nationally by 21%. During that same time, Virginia saw a decline by 3.5% (Source: TEConomy Partners, December 2018 VRIC presentation). A multi-pronged approach is necessary to engage industry collaboration around research, development and commercialization. For additional information, refer to Appendix D.

Industry Engagement Options for Collaboration
Foster industry-led talent development initiatives in conjunction with higher education.
Explore and encourage use of Other Transactions (OTs) within each focus area.
Develop a protocol to facilitate industry connections in real ways and on a routine basis: state level, regional and institutional level interfaces.
Encourage institutions to allocate a percentage of faculty workweek to engage with industry.

R&D Awareness/Marketing/Advocacy

Stakeholders generally expressed the need for more coordinated marketing, perhaps at the state level, to highlight research, development and commercialization successes to raise awareness and generate interest for additional, future collaboration and support.

Marketing efforts can connect with and support the research inventory development. Again, Appendix D outlines more details.

R&D Awareness/Marketing/Advocacy Options for Collaboration
Produce and deploy statewide high-level marketing plan and success stories as part of routine/consistent marketing effort by a designated state entity.
Develop an advocacy strategy to engage high profile leaders in each sector with ties to Virginia who will serve as advocates for research, development and commercialization efforts in the Commonwealth.
Facilitate and/or encourage regional and sector-based networking activities.

Additional Stakeholder Sentiments

As stakeholders provided input on options supporting the framework for collaboration, many shared other, related sentiments. First, that the efforts outlined in the Roadmap should build on existing relationships and expand to include economic development and enhanced private sector industry engagement. This includes building on work done by the Center for Innovative Technology and ongoing collaboration among the institutions of higher education.

Another stakeholder concern focuses on additional resources. For example, additional state funding for the higher education equipment trust fund, faculty recruitment, new research and lab facilities etc., toward research in these areas of focus is critical. In addition to enhanced state investment, stakeholders seek to ensure that the options for collaboration outlined are durable and supported over time to realize the Commonwealth's return on investment and build critical mass spanning any political changes.

MEASURING PROGRESS

While not a statutory requirement of the Roadmap, stakeholders indicated the importance of measuring progress as part of the process. The following are some of the questions posed regarding metrics of success.

- What does Roadmap success look like?
- How should progress be measured, success of the Roadmap's intent (areas of focus) and goal of collaboration?
- What are the most important metrics to measure progress?
- Is any data currently being collected and reported that can document progress?

Below is a list of potential means to measure Roadmap progress. An asterisk denotes those currently collected as part of the six-year planning process for the public institutions.

1. Percentage of research funding that Virginia receives by source.*
2. Number and funding amounts of research and commercialization grants received by the institutions.*
3. Capital outlay for relevant infrastructure.*
4. Entrepreneurial programs.*
5. Certificates by area of focus.
6. Degree completion by area of focus.
7. Number of students paid through externally funded research grants and contracts (within focus areas).*
8. Number of applicable academic units that have course requirements for capstones, experiential learning, internships.*
9. Government contracts awarded to Virginia businesses.
10. Faculty publications.
11. Patents filed.*
12. Patents pending.*
13. New licenses in Virginia.*
14. New licenses outside Virginia.*
15. New start-ups created in Virginia through institutional IP licensing.*
16. New start-ups created outside Virginia through institutional IP licensing.*
17. Number of jobs created by university start-ups.*

18. Number of new jobs (new companies).
19. Number of new jobs (expanding companies).
20. Total capital raised by higher education start-ups.
21. Venture capital funding in Virginia by sector.
22. Capital investment (new, indirect and induced).
23. Actual revenue.
24. Sales volume.
25. Top 5 or top 10 graduate schools in Virginia within each of the six focus areas.

*Collected broadly (not just areas of Roadmap focus) and reported as part of public institutions' six-year plans.

NEXT STEPS

The second phase of the roadmap development entails the research and development inventory component. The next step will be to form a separate working group to consult on the scope and use of the inventory, the inventory design process and implementation. This process will commence upon Roadmap approval.

CONCLUSION

The Commonwealth Research and Technology Strategic Roadmap identifies six areas of focus for research, development and commercialization activities: (1) life and health sciences; (2) autonomous systems; (3) space and satellites; (4) agricultural and environmental technologies; (5) cybersecurity; and (6) data science and analytics. Included in the Roadmap, a series of options will foster collaboration between higher education, economic development and private sector entities around these focus areas. The intended outcome of the strategic Roadmap is to best position the Commonwealth and its resources to grow Virginia's economy at large by growing its innovation economy.

ACKNOWLEDGEMENTS

The Commonwealth extends its sincere gratitude for the time, insight and support provided to SCHEV and VRIC by the following independent expert panelists throughout the process:

1. Dr. David Bowles, Executive Director, Virginia Institute for Spaceflight and Autonomy;
2. Aneesh Chopra, President, Care Journey, Inc.;
3. Dr. Eric Edwards, Co-Founder, Kaleo and Member of the Board of Directors, Activation Capital and Lighthouse Labs;
4. Dr. Jon Goodall, Professor and Associate Director of Link Lab, Department of Engineering Systems and Environment, University of Virginia;
5. Dr. Alfred Grasso, Immediate Past President and CEO, MITRE Corporation;
6. Tracy Gregorio, President, G2 Ops;
7. Richa Kaul, Managing Director of Services and Technology Sectors, Virginia Economic Development Partnership;
8. Kevin Pomfret, Partner, Williams Mullen and Director, Unmanned Systems Association of Virginia;
9. Jim Powers, Chairman and CEO, HemoShear Therapeutics;
10. Dr. Louise Temple, Professor, James Madison University School of Integrated Sciences;
11. Dr. Al Wicks, Associate, Applied Autonomy and Mechatronics Research Lab and Professor of Engineering, Virginia Tech;
12. Dr. Aurelia T. Williams, Professor of Computer Science and Executive Director, Cybersecurity Complex, Norfolk State University; and
13. Bill Wrobel, Human Exploration and Operations Mission Directorate, NASA.

Lastly, this process and product would not have happened without the candid input, follow up data and assistance from various stakeholders. On behalf of the Commonwealth, SCHEV and VRIC recognize, the chief research officers at the institutions for their ongoing collaborative efforts and support of the strategic roadmap development.

APPENDIX A: ROADMAP DEVELOPMENT TIMELINE AND PROCESS

TIMELINE AND PROCESS

The Roadmap development commenced in mid-March 2019 and progressed on the following chronology.

April - Identified and assembled panel of independent experts.

May 6 - Conducted outreach to institutions for research priority areas and supporting assets.

May 10 - Convened independent expert panel at SCHEV office for overview and initial discussion.

May - Conducted expert panel individual interviews.

May- June - Conducted stakeholder interviews.

July 2 and July 8 - Conducted second expert-panel convenings* on common themes from stakeholder input. * two meetings held with same content due to expert availability.

August 21 - draft Roadmap approved by SCHEV Council. Incorporated feedback.

September - Submitted Roadmap to required executive and legislative branch officials for review. Incorporated feedback.

October 8 - VRIC approval of Roadmap.

October – Submission of Roadmap to Governor Northam for final approval.

INDEPENDENT EXPERT PANEL

SCHEV assembled a panel of independent experts to consult on the Roadmap development process, identification of areas of focus and recommendations for aligning research and development and economic growth in the Commonwealth. Virginia Bio, Virginia Catalyst and the Virginia Academy of Science, Engineering and Medicine (VASEM) helped to identify potential candidates for the panel. VASEM put out a call for experts, and other entities provided names of individuals well qualified to participate.

More than 50 individuals expressed interest in participating on the panel. SCHEV screened their respective resumes and CVs for deep expertise in and broad awareness of research, commercialization and/or economic development. Candidate screening included a crosscheck to ensure, per statute, no panelist involvement in the submission, review or approval of any CRCF or VRIF applications within the last three years.

The expert panel included 13 volunteers spanning across Virginia's geographic footprint. Additionally, the members offered expertise in various industry sectors. Experts hailed from university basic and translational research labs, spin outs from higher education, scale ups from startup to large employers, to federal research centers and economic development.

The panel convened for the first time on May 10. The agenda included introductions, a presentation on baseline research, development and commercialization conditions, and initial discussions on areas of focus and metrics. In addition to the above, the panel developed a goal statement and goal-statement-focused actions.

Goal statement: *A successful Commonwealth Research and Technology Strategic Roadmap will serve as the framework to drive collaboration, commercialization and economic development activity in identified emerging and high growth sectors through research and strategic investment.*

Roadmap goal-statement-focused actions:

1. *Identify emerging and high growth sectors of focus. Where does Virginia win at present? Where should Virginia win? How should Virginia win in those areas? Why should Virginia win in those areas?*
2. *Develop the comprehensive and cohesive infrastructure for commercialization and economic growth in those sectors. This can include such aspects as talent pipeline, research and development inventory, collaboration, public-private partnerships, wrap around services from tech transfer, incentives, funding, mentoring and more.*
3. *Support inclusivity so that the subsequent economic growth opportunities benefit various parts of the Commonwealth and strengthen diverse assets and entities.*
4. *Increase the funding to support #1 and #2. Demonstrate success in #1 and #2 to leverage funding – more state funding, federal funding and industry funding around those areas. This will further deepen the identified domains.*

Individual panelist interviews allowed each panelist to provide input on research areas worthy of focus, options to achieve the goal of collaboration and metrics to measure success.

The second panel convening occurred on two dates – July 2 and July 8, due to expert availability. The meeting agenda centered on common themes from stakeholder engagement on areas of focus, options to achieve the statutory goal and metrics to measure success. The panel achieved consensus around areas of focus, vertical vs. horizontal areas, and priorities within each focus area where applicable.

STAKEHOLDER ENGAGEMENT

After the initial expert outreach, more than 35 different entities and individuals provided input. A sampling of some of the stakeholders includes:

- VRIC and SCHEV;
- Public and private institutions of higher education in the Commonwealth;
- Individual members of the National Academies of Sciences, Engineering and Medicine;
- Individual members of the Virginia Academy of Science, Engineering and Medicine;
- Federal research and development assets in the Commonwealth;
- Regional Technology Councils in the Commonwealth;
- Individual members of the Research and Technology Investment Advisory Committee;
- Selected staff of the Virginia Economic Development Partnership;
- Joint Commission on Technology and Science;
- Chairs of the House Appropriations Committee and Senate Finance Committee; and
- The private sector.

Stakeholders provided input on three topical areas – research areas of focus, options to achieve the goal of collaboration and metrics to measure success.

HIGHER EDUCATION RESEARCH PRIORITIES

Simultaneous to stakeholder outreach, SCHEV requested research priority lists from the chief research officers at each public institution. Specifically, per the Roadmap statute, SCHEV requested a list of each institution's research priorities that offer the most promise for applied research and commercialization. Institutional assets that support those priorities accompanied the research priority lists submitted. Examples of assets include but are not limited to eminent faculty, research centers, core labs and industry partnerships.

ROADMAP NARRATIVE DEVELOPMENT

Analyses of the higher education research priority lists included identifying areas of alignment with stakeholder input, VEDP and GO Virginia targeted sectors. A chart showing areas of alignment is included at the end of this appendix. This information along with quantitative data from various sources and frequency of stakeholder input shaped the research areas of focus for the Roadmap.

Qualitative and quantitative input also shaped the five core categories of options to achieve the Roadmap's goal of collaboration. Specifically, the Roadmap's goal, per statute, is to develop the framework to foster collaboration among higher education, economic development and private sector industries relative to the research areas of focus.

The Roadmap narrative content heavily focused on the research areas of focus and options for collaboration. Roadmap appendixes offered additional supporting data.

ROADMAP REVIEW PROCESS

SCHEV presented initial/draft areas of focus to SCHEV Council on July 16 for feedback. Between the July SCHEV Council meeting and August VRIC meeting, SCHEV staff met with staff of the money committees regarding areas of focus and core categories of options for collaboration. On August 13, SCHEV presented these same topics to VRIC and sought motion for approval to submit a draft to SCHEV Council and subsequently to the Governor, Chairs of the money committees and Joint Commission on Technology

and Science. The Roadmap statute specifies that such executive and legislative branch review occur at least 30 days prior to seeking formal approval of the Roadmap by VRIC. VRIC formally approved the Roadmap on October 8 and authorized its chair to submit to the Governor. The Governor has final approval authority.

EMERGENT THEMES: COMMON AREAS OF FOCUS				
VEDP Targeted Sectors	**GO Virginia Sectors (by region)**	**Institutional Priorities***	**Other Initiatives**	**Roadmap Areas of Focus****
Data centers, Software	Regions 1 and 4 (information technologies), Region 2 (information and emerging technologies), Region 3, Region 5 (business services and IT data centers), Region 6 (Information/data centers), Region 7 (computer services), Regions 8 and 9 (business services and IT)	Data analytics and intelligent memory and storage architectures (UVA), Integrated networking, communication and analytics (VT), Wireless and networking technologies, predictive analytics, fintech (Mason), Analytics, smart technologies, and biological data science (VCU), Small satellite data analytics (ODU), Software and high speed data acquisition hardware (CNU), Computer information systems (JMU), Big data (UMW)		Data science and analytics
Unmanned systems, Software	Region 2 (automotive), Region 5 (+ mod-sim), Region 7 (engineering services)	Sensors, sensor networks, urban technologies, nanomaterials, unmanned cyberphysical systems (Mason), Cyber and smart technologies (VCU), Systems of systems engineering, autonomous systems, AI/ML (VT), Systems engineering (ODU), IoT (W&M), AI, autonomy and IoT (JMU), Geospatial analysis (UMW)		Autonomous systems
Aerospace, Software	Region 5 (aerospace), Region 7 (engineering services)	Systems of systems engineering, autonomous systems, AI/ML, space systems (VT), Sensors, sensor networks, urban technologies, and		Space and satellites

EMERGENT THEMES: COMMON AREAS OF FOCUS				
VEDP Targeted Sectors	**GO Virginia Sectors (by region)**	**Institutional Priorities***	**Other Initiatives**	**Roadmap Areas of Focus****
		nanomaterials (Mason), Small satellite data analytics and systems engineering (ODU), IoT (W&M), Geospatial analysis (UMW)		
Cybersecurity, Software	Regions 1, 4 and 6 (information technologies) Regions 2 and 3 (information and emerging technologies), Region 5, Region 7, Regions 8 and 9 (business services and IT)	Cyber and Cyber physical, AI/ML (UVA and VT), Cyberphysical and cyber tools and technologies (Mason), Cybersecurity (VCU), Cybersecurity 5G (W&M), Cyberphysical (NSU), Cybersecurity and data intelligence analysis (JMU), Dalhgren specific research (UMW)	Commonwealth Cyber Initiative (CCI)	Cybersecurity
Life Sciences	Region 2, Region 3 (healthcare), Region 4, Region 6 (scientific services), Region 7, Regions 8 and 9 (biomed/biotech and health care)	Biocomplexity (UVA), Lifesciences, neuro and health technologies (VT), Biomedical devices and diagnostics, health tech, nanomaterials (Mason), Biopharma, cancer, addiction and neurosciences (VCU), Biomedical and synthetic biology (W&M), Cancer, diabetes, modsim health training, infectious diseases, neurology (EVMS), Community healthcare, addiction (opioid), virtual reality healthcare training, environmental and agricultural sustainability (JMU)	The Catalyst (VBHRC), Commonwealth Health Research Board (CHRB)	Life and health sciences

EMERGENT THEMES: COMMON AREAS OF FOCUS

VEDP Targeted Sectors	GO Virginia Sectors (by region)	Institutional Priorities*	Other Initiatives	Roadmap Areas of Focus**
Food & Beverage	Region 1 (agriculture and food and beverage manufacturing), Region 6 (aquaculture, commercial fishing and seafood processing), Region 8 (value-added food manufacturing), Regions 2 and 9 (food and beverage manufacturing)	Oyster restoration (CNU), Agricultural and environmental sustainability and oyster reef restoration (JMU), Aquaculture and urban agriculture (VSU)	VDACS, Institute for Applied Research and Learning	Agricultural and environmental technologies
N/A	Region 3 (high value natural resource products), Region 5 (shipbuilding and water technologies), Region 6 (forestry and water technologies), Region 7 (research organizations)	Digital Shipbuilding (ODU), ModSim (ODU), Offshore Wind (ODU), GreenTech/Environmental (W&M), AI (W&M), Renewable resources (CNU), Governance (NSU/HBCUs), Urban Tech - technologies for smart cities and resilient communities (GMU), Agricultural and environmental sustainability (JMU), Environmental sciences (UMW), Environmental studies (VCU)		

*Institutional priorities are specific to this Roadmap effort when asking each institution for a list of research priorities that offer the most promise for applied research and commercialization along with supporting assets.

** Based on common themes from research, institutional priority areas, VEDP targeted sectors and GO Virginia targeted sectors.

APPENDIX B: CONDITIONS INFLUENCING INNOVATION IN THE COMMONWEALTH

STATEWIDE RESEARCH AND DEVELOPMENT

Strong activity in research and development is the essential precursor to commercialization, startup and licensing activity. The Milken Institute's State Technology and Science Index (STSI) biannually ranks states by their capacity to turn research and commercialization efforts into high growth companies, high wage jobs and economic growth from innovation. The United States Economic Development Administration, in partnership with Harvard Business School, also has developed a cluster-mapping tool to assess research and development activity within metropolitan areas, states, and regions. Both of these tools examine Virginia's research and development performance.

Milken Institute's State Technology and Science Index

The Milken Institute uses data from over 107 indicators to compile the rankings into overall scores as well as relative to five composites: Research and Development Inputs, Risk Capital and Entrepreneurial Infrastructure, Human Capital Investment, Technology and Science Workforce and Technology Concentration and Dynamism. The rankings serve to facilitate policy recommendations to fill the tech talent pipeline or fund research infrastructure. The below is a summary of where Virginia stands relative to its peers overall and within each of the composite indices in 2018.

Milken Institute's State Technology and Science Index (STSI) Commonwealth of Virginia's Rankings			
	2016 Rank	2018 Rank	Unchanged Top 3 STSI
Overall STSI Rank (out of 50 states): 107 indicators compiled for the ranking.	9	12	1. Massachusetts
Research and Development Inputs: Measures a state's research capacity and ability to create knowledge.	20	16	2. Colorado
Risk Capital and Entrepreneurial Infrastructure: Measures entrepreneurial climate, risk capital access.	25	34	3. Maryland
Human Capital Investment: Components influencing this ranking include prevalence of certain degrees, state spending, SAT	7	8	
Technology and Science Workforce: This index focuses on the intensity of computer and information science experts, engineers and life and	8	8	
Technology Concentration and Dynamism: Factors include high tech employment, high tech business births, high performing tech companies and overall growth in the tech sector.	7	7	

Source: Milken Institute STSI Index.

Overall, Virginia ranked 12 out of 50 in 2018, down from ninth in 2016. Massachusetts, Colorado, and Maryland remained the unchanged top three from 2016. Within the Research and Development Inputs (RDI), Virginia **rose** from 20 to 16. RDI measures a state's research capacity and ability to create knowledge. This increase supports the growing education cluster in the Commonwealth. RDI is fundamental to an innovation economy. Milken based its RDI ranking on the following: federal, industry, and academic R & D expenditures along with National Science Foundation funding, small business technology transfer (STTR) awards and small business innovation research program (SBIR). The overall top three ranked states (Massachusetts, Maryland, and Colorado) also hold the top three spots for this composite index.

The Risk Capital and Entrepreneurial Infrastructure Composite Index shows Virginia **losing** nine spots, down from 25 to 34. This composite index measures the entrepreneurial climate, risk capital access etc. Sub-index components include the following: venture capital, small business investment company (SBIC) funds, incubators & accelerators, patents, business formation and clean/green/bio/nano tech investments. This downward ranking aligns with the findings by TEConomy Partners that illustrates a decline in early stage investment and venture capital.

The Human Capital Investment Composite Index identifies Virginia as **declining** by one point, from seven to eight, yet this index is one of the three indices that Virginia is included in the top 10. The tech talent initiative stemming from Amazon's announcement may influence these ratings in yet-to-be-determined ways. Sub-index components that influence this ranking are prevalence of certain degrees, state spending, internet access, and SAT scores.

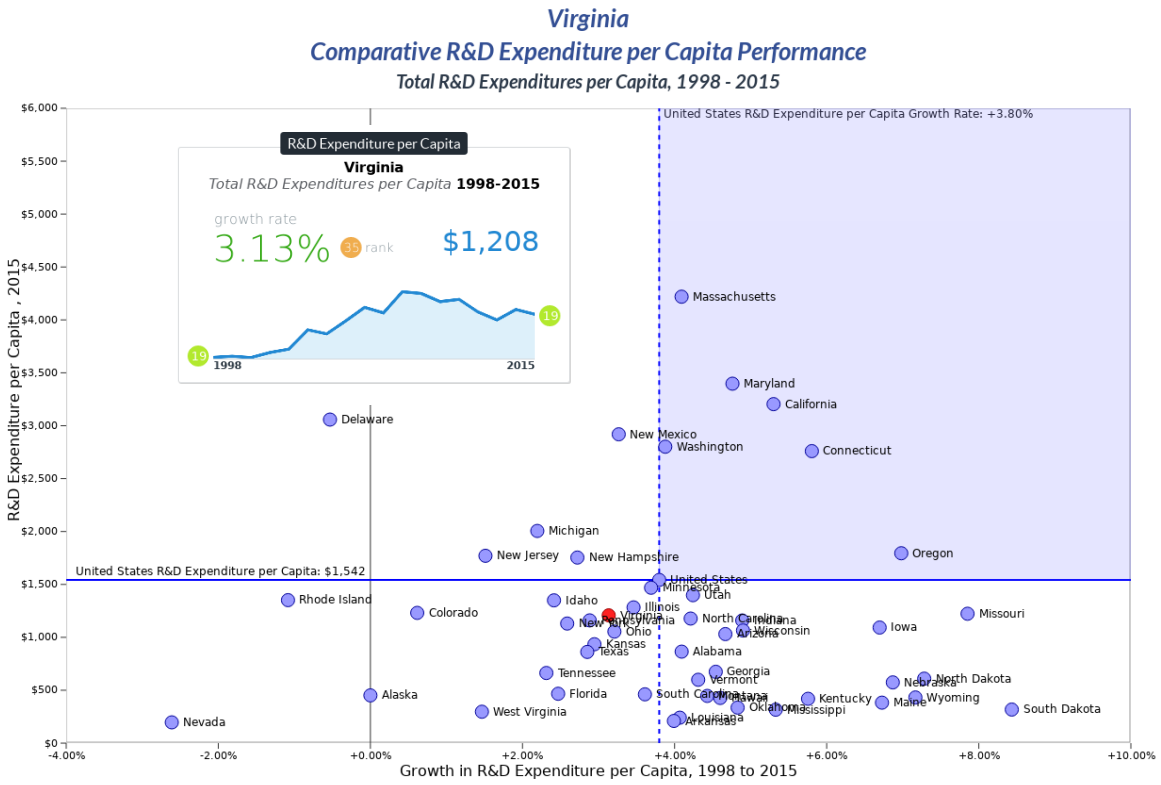
Virginia's rank of eight remains **unchanged** relative to the Technology and Science Workforce composite index. This index focuses on the talent pipeline that is essential for innovation and knowledge-based economic development. Components included in this index are intensity of computer and information science experts, engineers, and life and physical scientists.

Technology Concentration and Dynamism is the fifth and final composite index used to calculate overall rankings. For this specific composite, Virginia stays **static** at seven. Factors included in the composite are high tech employment, high tech business births, high performing tech companies, and overall growth in tech sector.

While Milken's 2018 overall ratings show Virginia in a mostly favorable light, the Commonwealth stepped higher in rankings for only one composite index - Research and Development Inputs. For the three rankings in the top 10, Virginia either dropped by one or stayed flat. Most importantly, the ecosystem index showed Virginia dropping from 24 to 36. Such a ranking suggests a weak entrepreneurial ecosystem that hampers the talent pipeline and research funding efforts, which could fuel innovation and commercialization if the ecosystem resources were more robust and favorable toward early stage and proof of concept funding.

United States Cluster Mapping Tool

Harvard Business School and the United States Economic Development Administration teamed up to launch U.S. Cluster Mapping, an interactive tool for economic developers, policy makers and industry to understand traded sector clusters relative to specific geographies and other economic data points. Below are selected graphics from this tool that show Virginia's overall standing relative to research and development.



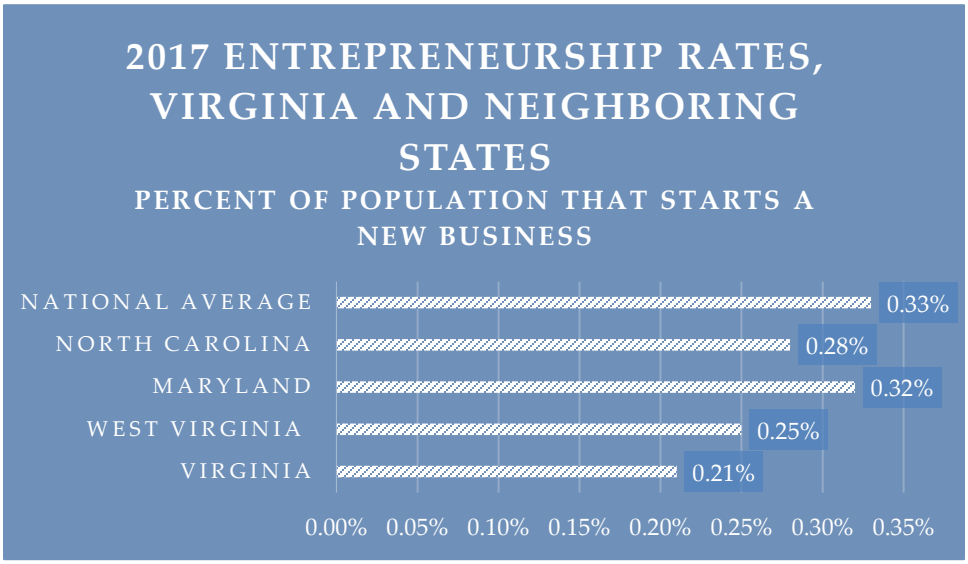
Source: U.S. Cluster Mapping Project, Institute for Strategy and Competitiveness, Harvard Business School. Data Sources.

The scatterplot and chart above visualize the same information. The data points show that Virginia ranks 35 in total R &D expenditures per capita and falls below the national average, as well as below the average growth rate in R &D expenditures.

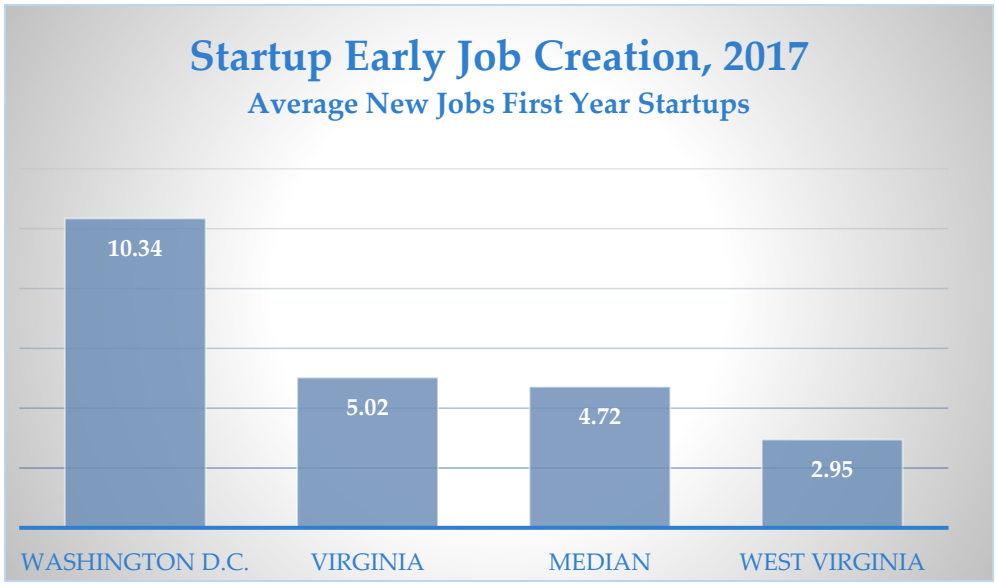
STATEWIDE INNOVATION

Entrepreneurship

A strong entrepreneurial environment supports ideation, commercialization and startup activity. The Kauffman Indicators provides data showing entrepreneurship trends in the United States. The following shows Virginia trailing neighboring states and the national average in terms of the percent of the population that starts a new business (all sectors, not just traded).



Source: Kauffman Indicators data calculated from the Census/Bureau of Labor-Statistics administered Current Population Survey.

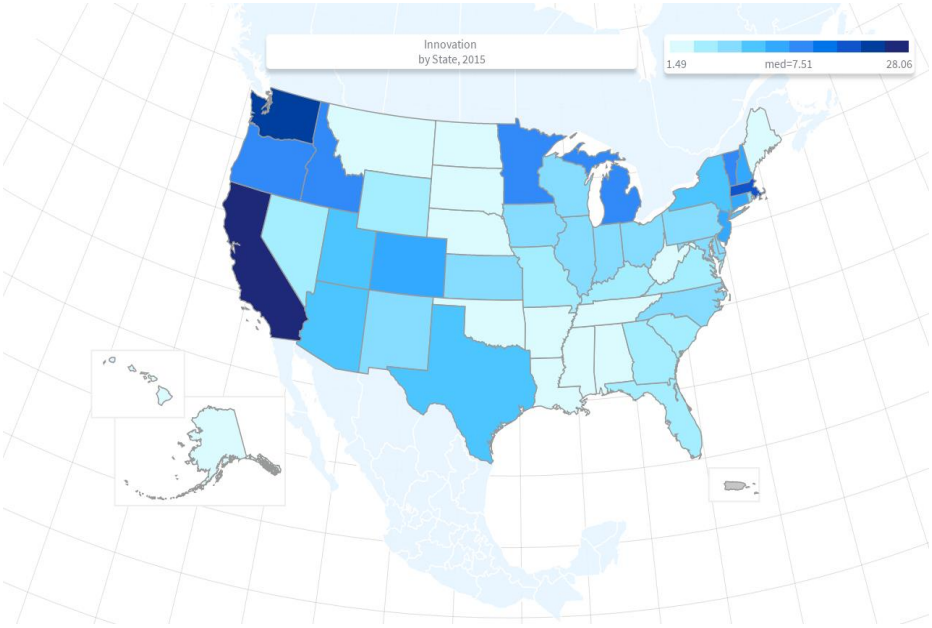


Source: Kauffman Indicators data calculated from the Census/Bureau of Labor-Statistics administered Current Population Survey.

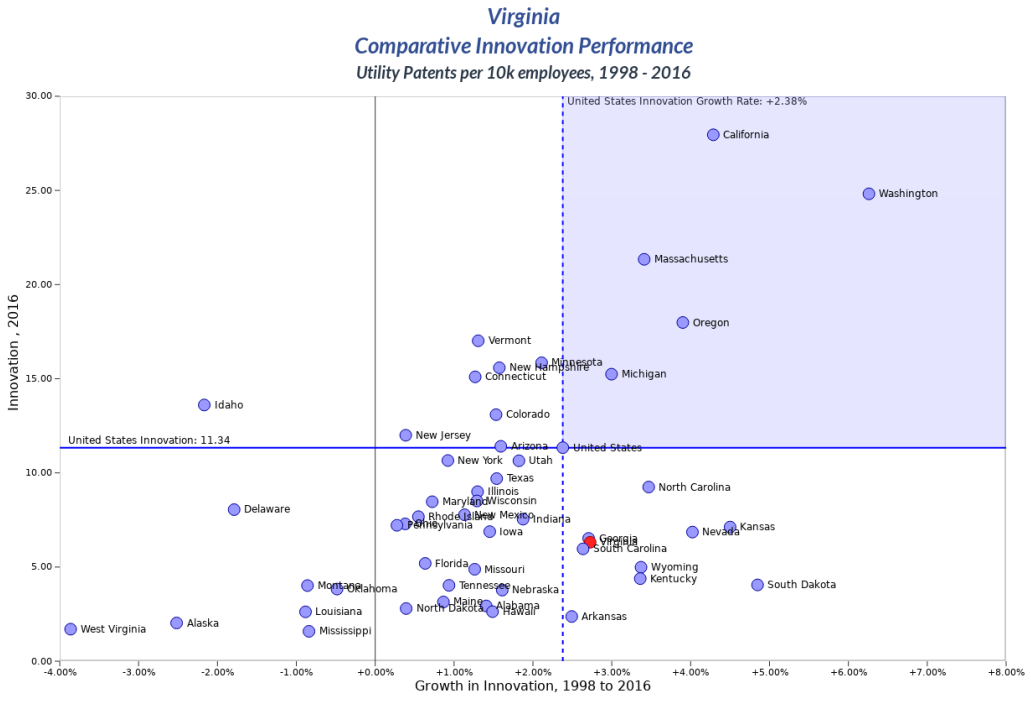
The startup early job creation graph compares high, median and low ranked states to Virginia in first-year startup job creation. While not a leader at growing entrepreneurs, when startups do take shape, Virginia yields above-average job creation. (Interestingly, Washington D.C. boasts a job creation level twice that of Virginia. It would be worthwhile to explore what is driving the high numbers in D.C., and how Virginia could capture more of that startup activity.)

Intellectual Property

Patent activity helps measure innovation activity in the state on a more basic level. Overall, patent activity per employee in Virginia is well below the national median. Utility patents per 10,000 employees indicates a similar standing for Virginia with the exception of a higher than average utility patent growth rate over a nine year period. This data suggests increased overall patent activity but still subpar to the national average. A complete listing of patents issued to Virginia entities over the past year is also included in this section.



Source: U.S. Cluster Mapping Project, Institute for Strategy and Competitiveness, Harvard Business School. Data Sources.



Source: U.S. Cluster Mapping Project, Institute for Strategy and Competitiveness, Harvard Business School. Data Sources.

For a detailed account of patent activity in Virginia, refer to these links:

Virginia Patent Activity by Locality https://www.uspto.gov/web/offices/ac/ido/oeip/taf/countyall/va_county_gd.htm

Virginia Patent Activity by Technology Class https://www.uspto.gov/web/offices/ac/ido/oeip/taf/stctec/vastcl_gd.htm

Virginia Patent Activity by Organization https://www.uspto.gov/web/offices/ac/ido/oeip/taf/stcasga/va_stcorg.htm

Patent Activity by NAICS by State https://www.uspto.gov/web/offices/ac/ido/oeip/taf/naics/naics_stc_fg5/naics_stc_fg.htm

Venture Capital Funding

Without funding, even the best ideas cannot yield new ventures. According to the National Venture Capital Association, Virginia ranks 16th in terms of venture capital investment. The ranking alone does not show the whole picture. Looking at the actual venture capital investment amounts compared to counterparts within the top 15 show Virginia receiving significantly smaller amounts.

VC Capital Invested ($M) by State as of 12//31/2018

	2014	2015	2016	2017	2018*
1. California	$38,567.70	$44,237.00	$43,023.80	$41,303.30	$77,297.60
2. New York	$6,388.10	$9,165.60	$9,394.60	$12,182.00	$14,311.80
3. Massachusetts	$5,042.60	$8,253.10	$7,098.40	$9,099.80	$11,885.70
4. Washington	$2,203.40	$2,090.30	$1,538.10	$1,740.40	$2,957.50
5. Texas	$2,628.50	$2,554.10	$2,033.20	$2,072.80	$2,686.70
6. North Carolina	$600.60	$1,305.80	$721.30	$998.00	$2,620.60
7. Illinois	$1,621.10	$1,457.50	$1,321.40	$2,045.70	$1,798.40
8. Florida	$1,716.40	$946.50	$1,538.90	$1,045.70	$1,735.20
9. Colorado	$1,173.90	$1,359.50	$1,111.10	$1,181.00	$1,635.90
10. Pennsylvania	$1,349.20	$1,042.60	$1,383.60	$1,036.10	$1,496.70
11. Maryland	$481.10	$904.20	$662.30	$552.80	$1,375.30
12. Utah	$1,065.10	$674.90	$899.30	$1,097.90	$1,165.20
13. Georgia	$707.10	$1,135.80	$616.00	$1,189.20	$1,147.30
14. Ohio	$479.50	$558.80	$368.90	$410.20	$1,026.20
15. Minnesota	$483.90	$624.40	$541.30	$618.70	$786.50
16. Virginia	**$586.00**	**$581.10**	**$525.70**	**$730.40**	**$742.70**
17. New Jersey	$866.70	$1,226.00	$706.90	$806.30	$732.00
18. Connecticut	$963.80	$467.40	$240.00	$526.80	$683.10
19. District of Columbia	$290.00	$470.10	$390.10	$640.00	$676.10

As of 12/31/2018

Source: PitchBook and National Venture Capital Association.

The same source shows Virginia with an elevated stature - at number 12 - in terms of venture capital deal count. Further analysis of both venture capital investments and deal flow illustrates a significant concentration of this activity primarily in Northern Virginia. Such is no surprise, but is nonetheless problematic for other Virginia regions.

VC Deal Count by State as of 12/31/2018

	2014	2015	2016	2017	2018*
1. California	3850	3816	3289	3332	3063
2. New York	1248	1256	1061	1107	1050
3. Massachusetts	662	742	605	647	660
4. Texas	557	594	517	466	427
5. Washington	307	369	299	348	366
6. Colorado	295	331	268	309	283
7. Pennsylvania	274	256	263	252	267
8. Illinois	283	276	286	265	253
9. Florida	303	275	240	265	234
10. North Carolina	157	199	147	185	185
11. Ohio	161	168	157	156	148
12. Virginia	**188**	**150**	**149**	**154**	**145**
13. Maryland	159	150	150	143	142
14. Minnesota	112	120	104	102	121
15. Georgia	186	168	132	144	120

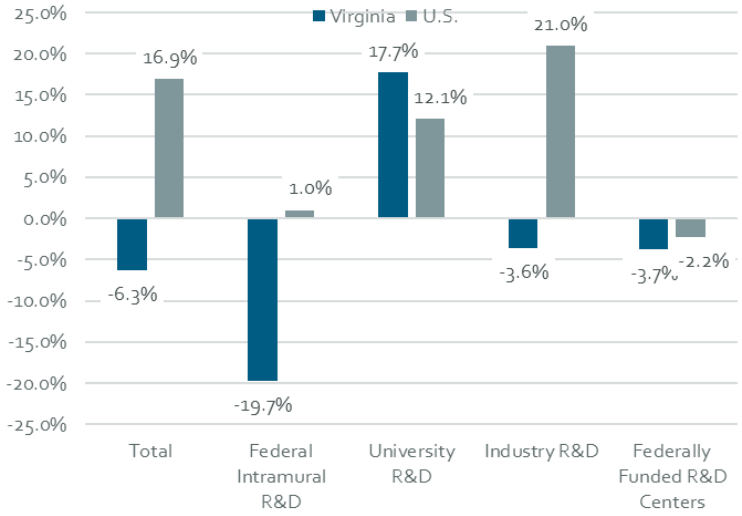
**As of 12/31/2018*

Source: PitchBook and National Venture Capital Association.

Industry Research and Development

Industry-led research and development is another critical component to the innovation ecosystem. This factor is perhaps Virginia's weakest attribute. The graph below produced by TEConomy Partners shows a significant discord between national trends in increased industry research and development and Virginia's contracting levels. Further examination is necessary to explain this disparity.

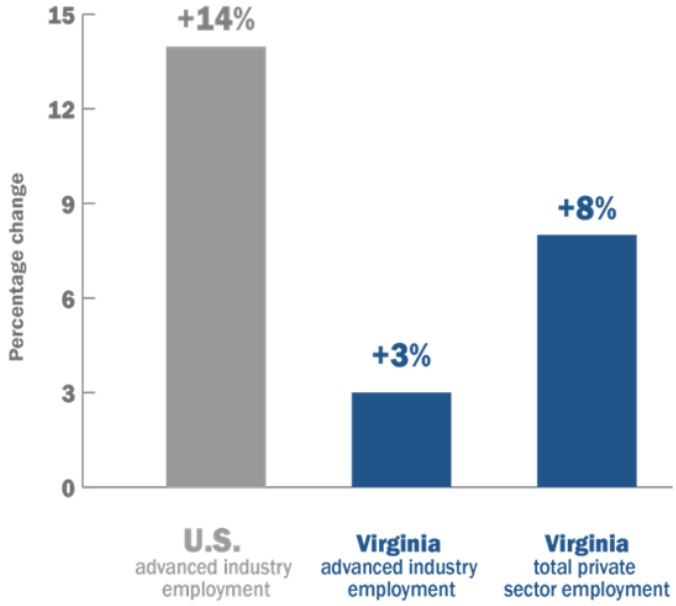
Declining Total Research Funding 2010-2015



Source: TEConomy Partners, December 2018 VRIC Presentation.

Not surprisingly, advanced industry growth in Virginia is also lower than the national average. Advanced industries include IT, software, clean and green tech, life sciences and healthcare, cybersecurity and advanced manufacturing. These tend to be higher skilled and high wage jobs. Without increasing industry R & D efforts, job growth in these advanced industries will remain low.

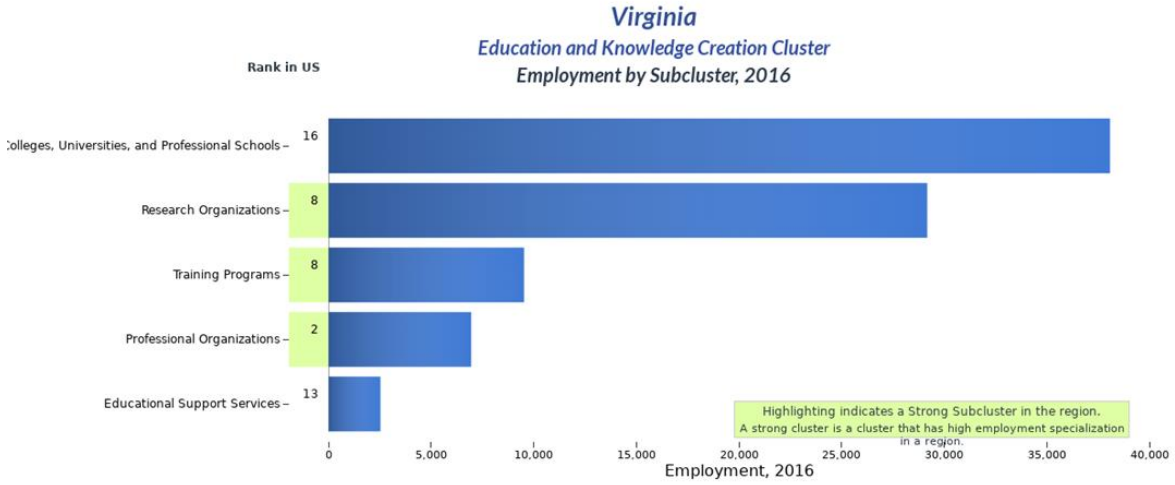
Lagging Growth in Advanced Industry Jobs 2010-2016



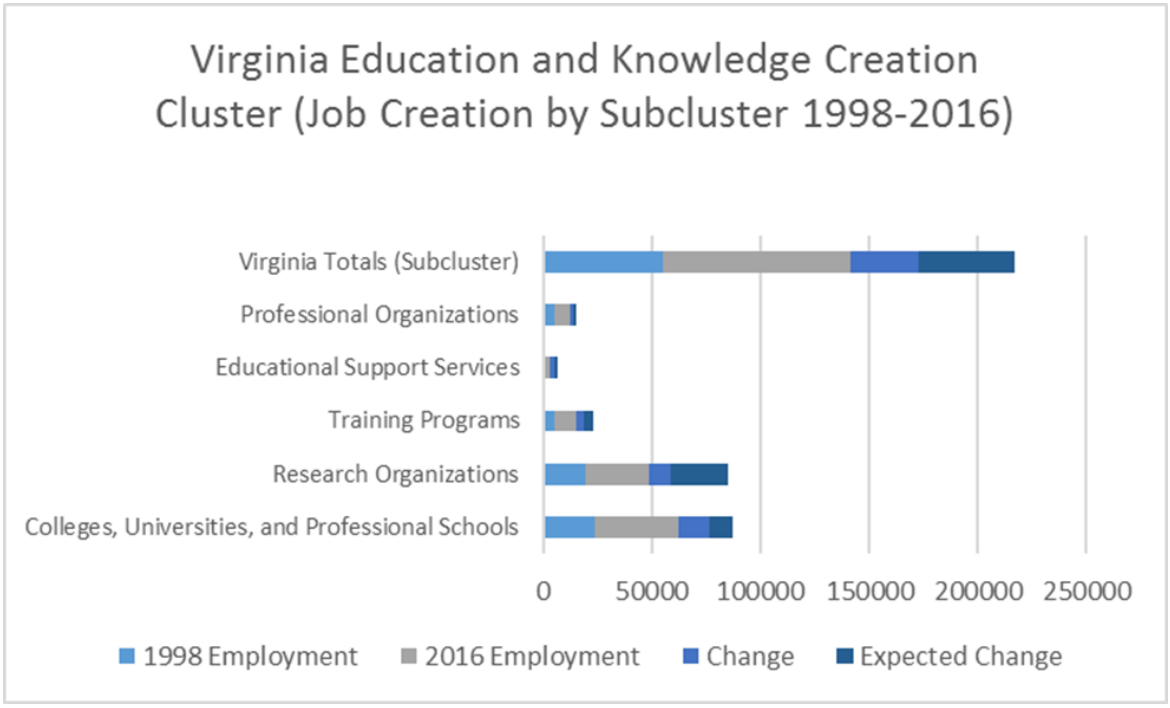
Source: TEConomy Partners, December 2018 VRIC Presentation.

Virginia's Education Cluster

Data from the United States Economic Development Administration and Harvard Business School identifies Virginia's education and knowledge creation cluster as a strong cluster from an employment perspective. For education subclusters, Virginia's research organizations rank eighth in the nation, and colleges and universities 16th. Without question, Virginia's higher education institutions and research organizations are poised to lead and coordinate research, development and commercialization efforts in the Commonwealth.



Source: U.S. Cluster Mapping Project, Institute for Strategy and Competitiveness, Harvard Business School. Data



Source: U.S. Cluster Mapping Project, Institute for Strategy and Competitiveness, Harvard Business School. Data Sources.

As excerpted below, VEDP's strategic plan further reinforces the strength of the Commonwealth's higher education institutions.

> "VEDP's most recent strategic plan highlights Virginia's competitiveness strongpoints and weaknesses as well as related strategies to accomplish its transformational goals.

Virginia's Economic Competitiveness Strengths (not exhaustive)

- Top 10 rankings for educational attainment, higher education and K-12.
- Impressive range of federal laboratories and higher education research.

Virginia's Economic Competitiveness Weaknesses (not exhaustive)

- Lack of customized workforce incentive program.
- Unusually high reliance on federal government-related activities.
- Limited commercialization of intellectual property."

Source: VEDP Strategic Plan Recap.

Higher Education Research and Development

With Virginia's strong higher education cluster, it is important to examine how the Commonwealth's higher education research and development activities compare to other states and institutions. The National Science Foundation (NSF) Higher Education Research and Development (HERD) survey data offer various vantage points.

In overall research and development expenditures, Virginia ranks number 14 out of all 50 states and territories. Taking that same information and looking at the ranking by individual institutions in Virginia, the data illustrates that almost 80 percent of the research and development expenditures come from three institutions: Virginia Tech (VT), University of Virginia (UVA) and Virginia Commonwealth University (VCU). The first two account for roughly 60 percent of the expenditures. The majority of those institutions' expenditures are concentrated in the life sciences (VT, UVA and VCU) and engineering (VT). This further reinforces the Commonwealth's Research and Technology Strategic Roadmap's areas of focus.

Higher Education R&D Expenditures, by State: FYs 2013–17

Rank	State	2013	2014	2015	2016	2017
	(Dollars in thousands)					
	United States	67,013,138	67,196,537	68,550,653	71,795,275	75,174,941
1	California	8,357,891	8,404,097	8,657,121	8,888,706	9,225,998
2	New York	5,519,542	5,638,584	5,700,230	6,075,419	6,359,672
3	Texas	4,813,050	4,898,443	5,036,366	5,254,298	5,495,483
4	Pennsylvania	3,361,374	3,328,851	3,356,723	3,950,378	4,179,810
5	Maryland	3,433,145	3,573,167	3,741,687	3,799,639	4,020,423
6	Massachusetts	3,532,767	3,500,516	3,673,620	3,796,681	3,927,934
7	North Carolina	2,739,920	2,814,943	2,814,924	2,937,671	3,081,568
8	Michigan	2,267,080	2,242,864	2,334,031	2,468,498	2,662,045
9	Florida	2,171,626	2,272,556	2,354,871	2,527,456	2,617,802
10	Illinois	2,501,413	2,327,098	2,382,947	2,400,990	2,503,276
11	Georgia	1,956,245	1,950,990	2,046,068	2,168,071	2,340,410
12	Ohio	2,168,267	2,158,565	2,152,796	2,193,019	2,299,112
13	Washington	1,561,573	1,537,190	1,548,580	1,645,843	1,740,919
14	**Virginia**	**1,419,504**	**1,381,078**	**1,411,176**	**1,462,939**	**1,551,003**

Source: NSF Higher Education Research & Development Survey.

Higher Education R&D Expenditures, Ranked by FY 2017 R&D Expenditures: FYs 2013–17

Rank	Institution	2013	2014	2015	2016	2017
	(Dollars in thousands)					
	All institutions	67,013,138	67,196,537	68,550,653	71,795,275	75,174,941
1	Johns Hopkins U.a	2,168,568	2,242,478	2,305,679	2,431,180	2,562,307
2	U. Michigan, Ann Arbor	1,375,117	1,349,262	1,369,278	1,436,448	1,530,139
3	U. California, San Francisco	1,042,841	1,084,031	1,126,620	1,294,261	1,409,398
4	U. Pennsylvania	828,422	828,350	864,068	1,296,429	1,374,293
5	U. Washington, Seattle	1,192,513	1,176,340	1,180,563	1,277,679	1,348,220
6	U. Wisconsin-Madison	1,123,501	1,108,564	1,069,077	1,157,680	1,193,413
7	U. California, San Diego	1,075,554	1,067,388	1,101,466	1,087,117	1,133,454
8	Duke U.	992,821	1,036,813	1,036,698	1,055,778	1,126,924
9	Harvard U.	1,012,766	933,975	1,013,753	1,077,253	1,123,160
10	Stanford U.	945,450	959,247	1,022,551	1,066,269	1,109,708
46	**Virginia Polytechnic Institute and State U.**	**496,169**	**513,149**	**504,282**	**521,773**	**522,425**
51	**U. Virginia, Charlottesville**	**385,828**	**358,576**	**373,218**	**397,458**	**469,682**
97	**Virginia Commonwealth U.**	**196,015**	**201,858**	**218,925**	**225,999**	**235,464**
146	**George Mason U.**	**95,913**	**98,680**	**106,410**	**108,899**	**112,404**
175	**Old Dominion U.**	**99,138**	**67,037**	**65,092**	**70,054**	**67,990**
177	**C. of William and Mary and Virginia Institute of Marine Science**	**57,940**	**59,015**	**61,554**	**63,027**	**64,127**

Out of 644 ranked institutions

i = imputed. na = not applicable; institution did not exist or did not exist as a separate entity. NA = not available; institution was not surveyed separately. ne = not eligible; institution did not meet the criteria for inclusion.

Source: NSF Higher Education Research & Development Survey.

Higher Education Innovation

SCHEV collects pre-HERD survey data as part of each institution's six-year plan reporting requirements. The six-year plan reporting spreadsheets include an economic development worksheet that captures the innovation activity spurred from higher education research and development. The data reported thus far, shows increased R &D

expenditures, licenses, startups and startup job creation. Disconcerting is the majority of licenses executed are outside of the Commonwealth. Similarly, a fair amount of the startup activity and associated jobs leave the state as well. This aspect needs further attention to keep this activity in Virginia.

Six-Year Plan Economic Development Performance Data		
Activity	FY2017	FY2018
R&D Expenditures*	$1,494,625	$1,534,587
Invention Disclosures	-	555
Patents Filed	-	168
Licenses Executed	102	141
In Virginia	-	32
Outside of Virginia	-	109
Start Ups Created	14	21
In Virginia	-	13
Outside of Virginia	-	8
Start Up Jobs Created	63	91
In Virginia	-	54
Outside of Virginia	-	37
* In thousands		

Source: Six-Year Plan Public Institution data from FY 2017 and FY 2018; Economic Development worksheet.

APPENDIX C: ANALYSIS OF STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS (SWOT), BY FOCUS AREA

Appendix C offers a detailed look at research and innovation strengths, weaknesses, opportunities and threats (SWOT analysis) in the Commonwealth, by focus area.

- Life and health sciences
- Autonomous systems
- Space and satellites
- Agricultural and environmental technologies
- Cybersecurity
- Data science and analytics

Unless noted in blue text, data pertaining to focus areas is sourced from TEConomy Partners "Research-Asset Assessment Study for Commonwealth of Virginia: Phase II Line-of-Site/Headwinds Analysis on Potential Growth Opportunities Leveraging Virginia's Research and Development Assets." This appendix includes reorganized, condensed and paraphrased data as necessary. For more information regarding TEConomy's data sources, methodology and synopses, please refer to the document above.

LIFE AND HEALTH SCIENCES

Sourced from TEConomy Partners "Research-Asset Assessment Study for Commonwealth of Virginia: Phase II Line-of-Site/Headwinds Analysis on Potential Growth Opportunities Leveraging Virginia's Research and Development Assets"

Reformatted, condensed and paraphrased as necessary.

Research Strengths

Leading publications fields with more than 1,000 research publications 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, and Health Care.

Major Grant Themes in Relevant R & D Areas

- Support grants for interdisciplinary oncology research at VCU and UVA cancer centers.
- Research on molecular pathways and mechanisms contributing to prevalence of major diseases in vascular and neurological areas.

Major Research Centers

- 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 School of Data Science; 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, MicroBiome Analysis Center (MBAC).

Research Weaknesses

No critical mass in specific research areas. Significant activity exists across the board but it is not concentrated or ranked in any one or two specializations whereby Virginia dominates.

Minimal emphasis on faculty creating value-driven technology outflows from university research centers given high amount of research expenditures.

Innovation Strengths

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- - 111 patent records, 0.53 specialization index, 0.55 forward citation impact index.

Leading Venture Capital Investment Areas (greater than $10M invested 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 Award 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.

Supporting Industry

- 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.

Innovation Weaknesses

- Lack of commercial wet lab space in some areas of the state 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.

Innovation Opportunities

Likely market applications aligned with Virginia's research and innovation strengths:

- 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. In addition, neurological disorders, comprising more than 600 conditions that affect the nervous system, affect 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%. Includes also 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.

Innovation Threats

- Many large bioscience companies that have achieved success and reached maturity in Virginia operate in niche markets that do not 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. 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

- 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 represent 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 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.

AUTONOMOUS SYSTEMS

Sourced from TEConomy Partners "Research-Asset Assessment Study for Commonwealth of Virginia: Phase II Line-of-Site/Headwinds Analysis on Potential Growth Opportunities Leveraging Virginia's Research and Development Assets"

Reformatted, condensed and paraphrased as necessary.

Research Strengths

Leading publications fields with more than 1,000 research publications 2014-2017

- Electrical/Electronic engineering - 4,304 publications, 1.16 specialization index.
- Applied Physics - 1,657 publications, .90 specialization index.
- Optics - 1,449 publications, 1.05 specialization index.
- Mechanical engineering - 1,144 publications, 1.26 specialization index.
- Meteorology/Atmospheric Sciences - 1,120 publications, 1.81 specialization index.

Major Grant Themes in Relevant R & D Areas

- IUCRC sites involving unmanned aerial systems and transportation systems testing.

Major Research Centers

- NASA Wallops Flight Facility.
- NASA Langley Research Center.
- Langley AFB, Quantico, Dahlgren, NAS.
- UVA: Commonwealth Center for Advanced Manufacturing, Multi-Functional Integrated System Technology (MIST) Center, UVA Applied Research Institute, LinkLab.
- VT: 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).
- ODU: Virginia Modeling, Analysis and Simulation Center (VMASC), National Center for System of Systems Engineering (NCSOSE), Virginia Institute for Spaceflight and Autonomy (VISA).
- Hampton: Virtual Parts Engineering/Modeling and Simulation (VPMAS).

Other Assets

Proximity of Port, Wallops flight facility, various branches of the armed forces – "teaming" and testing of interoperability, communication and command and control between land, air, and sea autonomous vessels.

Research Weaknesses

Various higher education research centers means potential for duplication of efforts and no understanding or coordination between institutions' centers. Capacities within each center are not known.

Minimal emphasis on faculty creating value-driven technology outflows from university research centers given high amount of research expenditures.

Innovation Strengths

Leading Venture Capital Investment Areas (greater than $10 million invested 2009-2016)

- Electronics and semiconductors: $127.96 million total equity invested (within Systems of Systems Engineering overarching domain).
- Industrial equipment: $12.3 million total equity invested 2009-2016.

Themes in SBIR Award Activity in Relevant R&D Areas

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

Supporting Industry

Significant industries, which support and are end users of innovation in this growth area (2009-2016)

- Engineering Services - 43,897 employees, 1.83LQ, -14% growth rate.
- Ship Building and Repair - 23,639 employees, 9.54 LQ, 1.6% growth rate.
- Heavy Duty Truck Manufacturing - 2,930 employees, 4.14 LQ, 70.5% growth rate.

- Search, Detection and Navigation Instruments - 2,930 employees, .83 LQ, -25% growth rate.

Innovation Weaknesses

- No leading areas of industry patent activity. Some work in navigational systems, optical components and electronics.
- Declining growth rate of engineering and navigational instrumentation employment base.
- Distributed assets across different and specific verticals and geographically makes growth of critical mass challenging.
- Constant pressure to relocate key industry and applied R &D efforts to areas in US with more integrated ecosystems.

Innovation Opportunities

Global market in integrated sensor systems technology:

- Automotive industry applications valued at $32 billion in 2017 CAGR of 11.4%.
- Process industry applications valued at $23.9 billion in 2017 CAGR 11.2%.
- Machinery equipment 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 11.5%.

North American market in unmanned systems technology:

- Unmanned aerial vehicle systems market valued at $155.9 million in 2015 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 CAGR of 11.3%.
- Climate research applications valued at $2.3 billion in 2017 CAGR of 9.5%.
- Infrastructure applications valued at $1.8 billion in 2017 CAGR of 6.6%.

- Security applications valued at $1 billion in 2017 CAGR of 5.3%.
- Oceanography applications valued at $480 billion in 2016 CAGR of 3.7%.

North American market for intelligent transportation systems technologies:

- Safety and risk management systems valued at $7 billion in 2017 CAGR of 16%.
- Vehicle telematics systems valued at $3.4 billion CAGR of 10.2%.
- Fleet and asset monitoring systems valued at $1.8 billion in 2017 with CAGR of 17.1%.

Likely market applications aligned with Virginia's research and innovation strengths:

- Embedded imaging and geospatial sensing systems.
- Unmanned autonomous systems sensors and command and control devices.
- Remote sensing networks for environmental, agricultural and defense applications.
- Intelligent transportation systems and vehicle automation.

Innovation Threats

- Challenge in achieving critical mass around innovation applications. Need for coordination of efforts and overarching branding identity around key verticals: space, small satellites and remote sensing.
- 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.
- 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 limits on employing foreign nationals and non-clear personnel and use of highly secure infrastructure) that can hamper growth of business operations.

Potential Development Pathways

- Establish University Affiliated Research Center (UARC) by the Department of Defense (DoD). Explore potential for this at a Virginia engineering university and conduct needed strategic planning exercise.

- Develop an industry attraction fund that includes cost of new infrastructure for such sectors.
- Explore public-private partnerships for shared use industry-university applied research centers.
- State-funded "grand challenge" competition in key areas similar to Defense Advanced Research Projects Agency (DARPA) to raise visibility of the state's engineering ecosystem.
- Modify tenure requirements to encourage commercialization activities.
- Develop incentive for attracting young talent and/or eminent faculty.
- Identify segments or process/protocol to identify segments for competitive grant applications.

SPACE & SATELLITES

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Reformatted, condensed and paraphrased as necessary.

Research Strengths

Leading publications fields with more than 1,000 research publications 2014-2017

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- Optics - 1,449 publications, 1.05 specialization index.
- Mechanical engineering - 1,144 publications, 1.26 specialization index.
- Meteorology/Atmospheric Sciences - 1,120 publications, 1.81 specialization index.

Major Grant Themes in Relevant R & D Areas

- Collaborative research in space weather and atmospheric sensing.

Major Research Centers & Assets

- NASA Wallops Flight Facility.
- NASA Langley Research Center.
- VA Space Mid-Atlantic Regional Spaceport (MARS).
- Jefferson Lab.
- Dahlgren Havel Surface Warfare Center.
- 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, LinkLab.
- VT: Institute for Critical Technology and Applied Science (ICTAS), 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 and Simulation Center (VMASC), National Center for System of Systems Engineering (NCSOSE), Virginia Institute for Spaceflight and Autonomy (VISA).
- Hampton: Virtual Parts Engineering/Modeling and Simulation (VPMAS).

Research Weaknesses

- Various higher education research centers means potential for duplication of efforts and no understanding or coordination between institutions' centers. Capacities within each center are not known.
- Minimal emphasis on faculty creating value-driven technology outflows from university research centers given high amount of research expenditures.

Innovation Strengths

Leading Venture Capital Investment Areas (greater than $10 million invested 2009-2016)

- Electronics and semiconductors: $127.96 million total equity invested (within Systems of Systems Engineering overarching domain).

Themes in SBIR Award Activity in Relevant R&D Areas

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

Supporting Industry
Significant industries, which support and are end users of innovation in this growth area (2009-2016).

- Engineering Services - 43,897 employees, 1.83LQ, -14% growth rate.
- Search, Detection and Navigation Instruments - 2,930 employees, .83 LQ, -25% growth rate.

Innovation Weaknesses

- No leading areas of industry patent activity. Some work in navigational systems, optical components and electronics.
- Declining growth rate of engineering and navigational instrumentation employment base.
- Distributed assets across different and specific verticals and geographically makes growth of critical mass challenging.
- Constant pressure to relocate key industry and applied R &D efforts to areas in US with more integrated ecosystems.

Innovation Opportunities

Global market in integrated sensor systems technology:

- Machinery equipment 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 11.5%.

Global market in remote sensing platforms:

- Disaster management applications valued at $2.3 billion in 2016 CAGR of 11.3%.
- Climate research applications valued at $2.3 billion in 2017 CAGR of 9.5%.
- Infrastructure applications valued at $1.8 billion in 2017 CAGR of 6.6%.
- Security applications valued at $1 billion in 2017 CAGR of 5.3%.
- Oceanography applications valued at $480 million in 2016 CAGR of 3.7%.

Likely market applications aligned with Virginia's research and innovation strengths:

- Embedded imaging and geospatial sensing systems.
- Sensors and command and control devices.

- Remote sensing networks for environmental, agricultural and defense applications.

Innovation Threats

- Challenge in achieving critical mass around innovation applications. Need for coordination of efforts and overarching branding identity around key verticals: space, small satellites and remote sensing.
- 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.
- 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 limits on employing foreign nationals and non-clear personnel and use of highly secure infrastructure) that can hamper growth of business operations.

Potential Development Pathways

- Establish University Affiliated Research Center (UARC) by the Department of Defense (DoD). Explore potential for this at a Virginia engineering university and conduct needed strategic planning exercise.
- Develop an industry attraction fund that includes cost of new infrastructure for such sectors.
- Explore public-private partnerships for shared use industry-university applied research centers.
- State-funded "grand challenge" competition in key areas similar to Defense Advanced Research Projects Agency (DARPA) to raise visibility of the state's engineering ecosystem.
- Modify tenure requirements to encourage commercialization activities.
- Develop incentive for attracting young talent and/or eminent faculty.
- Identify segments or process/protocol to identify segments for competitive grant applications.

AGRICULTURAL AND ENVIRONMENTAL TECHNOLOGIES

Feedback from the majority of stakeholders interviewed identified this as one area of focus for the Roadmap. The other areas of focus exhibit historical R&D traction and supporting data. This area, however, is important to Virginia's economy and will continue to grow in importance in the future. Virginia's stakeholders want to better position Virginia to cultivate opportunities in this area. Those with experience at federal research agencies have reinforced this perspective.

SCHEV staff conducted the SWOT analysis for this area of focus. A significant portion of the SWOT analyses for the other five areas came from TEConomy Partners assessment study and its respective data sources. Therefore, this SWOT analysis will not be the same in terms of sourcing and content.

Taking a broad view, with the world's population growing from 7 billion to nine billion by 2050, rising temperatures and growing antibiotic resistance, a tremendous need exists for scientists, researchers and practitioners to come together and solve these intertwining agricultural and environmental global issues. One Medicine One Science (OMOS) exemplifies one aspect of this emergent area - the intersection of agriculture and the environment as it relates to human health, sustainability and resilience.

Research Strengths

Major Research Centers and Assets

- Institute for Advanced Learning and Research (IALR) - Plant endophyte research center, precision agriculture.
- Hampton Roads RISE Resilience Innovation Center.
- NASA Langley Research Center.
- Jefferson Labs.
- Commonwealth Center for Recurrent Flooding Resilience (ODU, W&M and VIMS).
- VT: Virginia Agricultural Experiment Station, Mahindra AgTech Center, Smart Farm Innovation Network, Coastal Hazards (Dr. Jennifer Irish).
- UVA: Link Lab, Environmental Resilience Institute (Dr. Scott Doney, previously from Woods Hole Research Station and Dr. Laurence Band from UNC-Chapel Hill).
- VSU: Agricultural Research Station/Randolph Farm.
- W&M: Virginia Institute for Marine Science.

- VCU: Rice Rivers Institute, Dr. Sriram Rao (OMOS concept, previously from UMN).
- GMU: Institute for a Sustainable Earth.
- ODU: VMASC, Mitigation and Adaptation Research Institute, Dr. Larry Atkinson (Ocean, Earth and Atmospheric Sciences), Virginia Sea Grant (Michelle Covi).

Research Weaknesses

Lack of critical mass of research, development and commercialization activity in agricultural and environmental technologies. This includes publications, patent activity and SBIR activity. Much of the capabilities, work by recruited eminent scholars and grant-funded efforts are still at the early stages of growth and build out.

Innovation Weaknesses

No leading or substantial areas of industry patent activity. Some work in navigational systems, optical components and electronics as these pertain broadly to satellites and autonomous systems that may or may not relate to precision agricultural and environmental technologies.

Innovation Strengths

Themes in SBIR Award Activity in Relevant R&D Areas*

- Sonar, acoustic, ocean/naval sensing technologies.
- High performance antennas, radars, lidars, integrated optics and sensing units.

Supporting Industry*
Significant industries, which support and are end users of innovation in this growth area (2009-2016)

- Engineering Services - 43,897 employees, 1.83LQ, -14% growth rate
- Search, Detection and Navigation Instruments - 2,930 employees, .83 LQ, -25% growth rate

*broadly pertain to satellites and autonomous systems that may or may not relate to agricultural and environmental technologies.

Innovation Opportunities

Agricultural technologies (AgTech): In 2018, venture capital investment in AgTech topped more than $1.6 billion. The United States has seen continued year over year increase in the percentage of venture capital deals funded globally in this area. The median AgTech venture capital deal was $2.5 million. A breakdown by subvertical markets for venture capital funding in 2018 (through October 31, 2018) is included below, sourced from Pitchbook.

- Plant sciences: The modification of existing plants and organisms to improve plant health and yield, including plant-breeding, development of novel traits, genetic modification/editing, and more. $171.6 million (13 deals).
- Animal technologies: Hardware and software systems specifically designed to enable management of livestock and other farm animals in general, with use cases ranging from monitoring of health to more efficient harvesting of related resources. In addition, technologies aimed at improving formulation of animal feed and medicines are included, ranging from veterinary drug applications to the entire nutritional spectrum. $125.8 million (22 deals).
- Crop protection and input management: The development of products and technologies that when applied improve plant yield, including the development of synthetic and natural active ingredients, biologicals, formulations, seed treatments, and nutrient technologies to improve plant or soil health and reduce other inputs. $576.6 million (14 deals).
- Imagery: Equipment, software and hardware systems plus actual manufacturing of drones and satellites for aerial monitoring. $142.1 million (19 deals).
- Indoor agriculture: The production of turnkey software and hardware systems designed for the cultivation of crops within buildings, often focused on either residential or commercial real estate markets, as well as related services and building of infrastructure. $146 million (29 deals).
- Ag marketplace and fintech: Online marketplaces for the trading, buying and selling of agricultural goods, as well as platforms for the management of related financial transactions and administration of business relationships. $56.5 million (10 deals).
- Precision agriculture: The building of software suites, data management and analytics tools for improved farm management, including the measurement of crop inputs, soil, moisture, weather, inventory, etc., typically within the realm of enterprise suites with user-friendly mobile capabilities. $41.8 million (18 deals).
- Sensors and smart farm equipment: Hardware and software systems specifically designed to monitor a range of conditions, most frequently within close

proximity, plus equipment for farming, with integrative capabilities for whole platforms. $63.1 million (28 deals).
(Source: AgTech Investment Review)

Much of the commercialization activity and growth in this area comes from industry conglomerate acquisition of startups with innovative technologies. The AgTech sector as a whole is scaling up and emerging. While North Carolina and several Midwestern states dominate, an opportunity exists for Virginia to rise in stature and contribute meaningfully to research and innovation in this sector.

A significant opportunity also exists to foster a stronger relationship with North Carolina around this area to become a significant collective research force. Earlier this year, North Carolina collaborated with Virginia to hold an AgBio conference.

Environmental technologies:

Global market in remote sensing platforms:*

- Disaster management applications valued at $2.3 billion in 2016 CAGR of 11.3%.
- Climate research applications valued at $2.3 billion in 2017 CAGR of 9.5%.
- Infrastructure applications valued at $1.8 billion in 2017 CAGR of 6.6%.
- Oceanography applications valued at $480 million in 2016 CAGR of 3.7%.

*broadly pertain to satellites and autonomous systems that may or may not relate to agricultural and environmental technologies.

Innovation Threats

For Virginia to be competitive in this sector, it must work collaboratively with North Carolina. Attempting to "go it alone" or compete with North Carolina will bear less fruitful outcomes from research, development and commercialization efforts.

Potential Development Pathways

Through state-level leadership and/or a public-private partnership, foster collaborative research, development and commercialization activities with North Carolina around this focus area.

CYBERSECURITY

Sourced from TEConomy Partners "Research-Asset Assessment Study for Commonwealth of Virginia: Phase II Line-of-Site/Headwinds Analysis on Potential Growth Opportunities Leveraging Virginia's Research and Development Assets"

Reformatted, condensed and paraphrased as necessary.

Research Strengths

Leading publications fields with more than 1,000 research publications 2014-2017

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

Major Grant Themes 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.

Major Research Centers

- 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).
- COE-CS - Center of Excellence in Cybersecurity with an emphasis on modeling, simulation, analysis and experimentation (collaborative between NSU and ODU-VMASC).
- MITRE - National Cybersecurity FFRDC
- Commonwealth Cyber Initiative (VT Hub and Node certification underway).

Research Weaknesses

Various higher education research centers means potential for duplication of efforts and potential lack of coordination between institutions' centers. Capacities within each center are not clear. The Commonwealth Cyber Initiative (CCI) should help provide more coordination, collaboration and focus.

Minimal emphasis on faculty creating value-driven technology outflows from university research centers given high amount of research expenditures.

Innovation Strengths

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 (greater than $10M invested 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 Award 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.

Supporting Industry

Through a collaborative effort with Burning Glass and CompTIA, the National Institute for Standards and Technology (NIST) maintains the CyberSeek database on Virginia employment in cybersecurity jobs. It reports that, as of August 2017, Virginia 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.

Innovation Weaknesses

- How to achieve adequate levels of skilled talent supply to meet rapidly increasing demand for cyber security skillsets by industry.
- How to provide employers with access to Virginia's university research base 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.
- How to shift Virginia's economy from cyber security service-oriented companies toward product-oriented companies that are more likely to self-invest in R&D.
- How to improve strategic partnerships between universities and industry beyond their current level.

Innovation Opportunities

- 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%.

Likely market applications aligned with Virginia's research and innovation strengths:

- 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 device.

Innovation Threats

- Ongoing separation between university and industry R&D efforts in the state and low levels of self-financed R&D by industry.
- Effects of proximity unique to Washington, DC ecosystem and large government client bases.
- Ongoing shift from culture of intellectual property protection for revenue generation towards technology commercialization and value creation.
- Regional nature of Virginia's industry and research assets base.

Potential Development Pathways

- 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.

- 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 cybersecurity 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.
- Accelerating Virginia's position as a cybersecurity 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 cyberphysical technologies outside of DC metro area to help spread industry innovation footprint.

DATA SCIENCE AND ANALYTICS

Sourced from TEConomy Partners "Research-Asset Assessment Study for Commonwealth of Virginia: Phase II Line-of-Site/Headwinds Analysis on Potential Growth Opportunities Leveraging Virginia's Research and Development Assets"

Reformatted, condensed and paraphrased as necessary.

Research Strengths

Leading publications fields with more than 1,000 research publications 2014-2017

- Electrical/Electronic Engineer - 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.

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

Major Grant Themes 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.

Major Research Centers

- UVA: UVA School of Data Science, 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 @ Virginia 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.

Research Weaknesses

- 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.

Innovation Strengths

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.

Leading Venture Capital Investment Areas (greater than $10M invested 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 Award 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.

Supporting Industry

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.

Innovation Weaknesses

- 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 place making 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.

Innovation Opportunities

- 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% of Consumer goods and retail services market valued at $9.9 billion in 2015 with CAGR of 1.9%.

Likely market applications aligned with Virginia's research and innovation strengths:

- Integrated networking solutions o 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 and 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.

Innovation Threats

- Ongoing separation between university and industry R&D efforts in the state and low levels of self-financed R&D by industry.
- Effects of proximity unique to Washington, DC ecosystem and large government client bases.
- Ongoing shift from culture of intellectual property protection for revenue generation towards technology commercialization and value creation.
- Regional nature of Virginia's industry and research assets base.

Potential Development Pathways

- 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 an excellent 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 the state possesses a variety of strength areas in developing innovative data analytics technologies, these centers of excellence should align closely 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.
- Institutions with data center computing capacity could provide startups with access to "cloud" via some mutually beneficial agreement.
- Collaborate with startups and industry to share AI and ML basic research algorithms for application and real use.

APPENDIX D: OPTIONS FOR COLLABORATION

The identification of six research areas worthy of focus sets the context for achieving the goal of the Roadmap - creating a framework to facilitate collaboration between higher education, private sector industry and economic development around those foci. The Roadmap's statutory goal encourages collaboration along the continuum from basic research through to commercialization.

Through the stakeholder input process and in consultation with the panel of independent experts, five core categories for options to facilitate collaboration emerged:

- Research inventory;
- Capacity building;
- Talent development;
- Industry engagement; and
- Awareness/marketing/advocacy.

The comprehensive list and details of each core category is included below. Options are means to achieve the Roadmap's statutory goal of collaboration.

RESEARCH INVENTORY

The Roadmap statute requires establishment of a research and development inventory. After completion and approval of the Roadmap, and consistent with existing code requirements, SCHEV will follow a similar process to develop the research inventory.

The scope of such an inventory can vary widely. The implementation of an inventory can also inform future roadmaps and areas of focus for the Commonwealth as well as tie into and support the other core categories of options for collaboration outlined in this appendix.

Research Inventory Options for Collaboration
Develop a portal and identify equipment, biorepository, core labs and other assets for sharing/use. Connect with relevant, existing sites and building inventories where appropriate. • The Virginia Catalyst has already begun this effort via a memorandum of understanding with various higher education institutions. The inventory could build on this work and broaden the scope. • The portal could also list state authority-owned properties –for flex, lab, wet lab and other space for startups. One model mentioned is Georgia Tech's Advanced Technology Development Center.
Develop a portal of statewide available technologies and IP. • This can build up over time and focus initially on roadmap sectors. • Additional use as an industry attraction tool. • Refer to economic development and commercialization advancement sections for more information. • Explore state purchase and licensing of a research, development and commercialization inventory web-based platform. Academic Analytics, **Wellspring** or other comparable, web-based platforms.
Create a comprehensive and cohesive research and development inventory. This would enable identification of faculty by area of focus and research activity along with available IP, shared equipment, clinical trial information, associated startups and a marketing component. For this tool, clear, uniform taxonomy is essential for use. • Georgia Research Alliance is commonly referenced model. • Implementing a comprehensive approach (the entire above plus "site miners" or human components to facilitate engagement and ease of use). Extremely time and cost intensive. Ohio Innovation Exchange is such a model. • Academic Analytics, **Wellspring**, Digital Science, Reed Elsevier and others offer robust inventory platforms. **Crunchbase** by Wellspring offers investor-scouting capabilities and market research for associated startups.
Provide dedicated resources to develop the research and development inventory.

CAPACITY BUILDING

The most frequent stakeholder input centered on building the Commonwealth's research, development and commercialization capacity in a variety of ways to yield more cohesive and collaborative results.

Resource Alignment

Alignment of resources was top of mind after the 2019 General Assembly legislative session and three bills intending to overhaul and streamline resources for research, development and commercialization. The vast majority of stakeholder input supported a more streamlined and coordinated process.

Three iterations of resource alignment input include:

Resource Alignment Options for Collaboration.
Concept 1: Aggregating existing programs, funding and associated processes and databases.
Concept 2: Deploying a hub and node model (either centralized or via area of focus).
Concept 3: Implementing new programs addressing stakeholder needs/requests such as proof of concept programs and commercialization advancement plans.

Economic Development

Stakeholders indicated the need for more collaboration with economic development entities to serve as a primary connector between university innovation and industry engagement. The table includes specific activities.

Economic Development Options for Collaboration
Develop a process and establish an economic development point of contact for routine review of technology portfolios with technology transfer offices (TTOs) and Chief Research Officers at the public higher education institutions, to inform state-level business development efforts. • Broaden portfolio review to include TTOs from the Commonwealth's federal research centers. • Use portfolio review to inform and support state prospect activity, existing business engagement and to form new partnerships.
Add acquisition assistance to state economic development activities where licensing of technologies developed by faculty could drive existing industry growth or prospect activity through acquisition. • Provide dedicated resources for mergers & acquisition implementation. • Provide dedicated resources for "matchmaking" assistance between higher education licensing opportunities and business expansion and attraction clients.
Foster formation of a Mid-Atlantic alliance for research, development and commercialization in aligning areas of focus. • Develop a short-term plan and/or public private partnership to facilitate Mid-Atlantic alliance formation for research, development and commercialization in aligning areas of focus (e.g., agricultural technologies). • Build from recent work between Virginia and North Carolina, for example, with joint Ag Bio 2019 conference.
Work with various economic development organizations to leverage opportunity zones, enterprise zones and other designated development areas in the Commonwealth. • Use to spur further revitalization from above efforts where it is strategic and appropriate. • For example, assist with startup space or a research asset's location within one of Virginia's designated development zones.

Commercialization Advancement

Commercialization advancement measures are integral to build capacity at the institution and statewide levels.

Commercialization Advancement Options for Collaboration
Design sector-based technology transfer office (TTO) collaborative agreements among institutions. • Depending on activity at each institution, this can be cost beneficial for institutions to use as a "pay for services" approach. • Consider using an existing R&D funding program to cultivate/support TTO collaborative agreements around the six areas of focus. • For example, two institutions jointly apply to lead life and health sciences TTO collaborative agreement while other institutions lead other areas of focus. • Cultivating sector-based collaborative TTO agreements builds capacity across the state, levels the playing field through pay for services access as needed and deepens expertise by area of focus.
Create a statewide industry sponsored research agreement between institutions and industry. • Designate state entity(ies) to lead effort and work with Chief Research Officers and TTOs to develop a statewide agreement. Entities can also market this once developed, as can the institutions. • Current work between SCHEV and VEDP regarding MITRE Corporation's University Innovation Exchange has laid the groundwork for this.
Produce statewide portfolio of intellectual property (IP) across all universities. • Designate an entity to convene institutions to explore support, process and cost. • Compliments development of research and development inventory and technology portfolio review depending on its scope. • Uses are multiple from opportunity to "bundle" patents, access to economic development and other state entities for portfolio review. • Enables review by various state R&D funding programs to assess innovation activity in areas of focus.
Develop templates/share of best practices/regional staffing agreements where appropriate. • Work with the Commonwealth's higher education institutions and other appropriate partners to share any technology transfer templates and best practices. • Based on this information and commercialization advancement plans, promote regional staffing agreements where necessary to improve capacity. For example, sharing of a tech transfer office marketing position across multiple, institutions.
Explore statutory language regarding state funds for patents and patent resource allocation. • Seek counsel review of statutory language, current purview. • Input to use state funding to pay for some portion of an institution's patent activity.
Consider changes to state R&D tax credit qualification to increase research and development expenditures and commercialization activities. • Consider additional analysis of current incentive usage to inform potential modifications. • Examine other states' formulas for similar incentives. • Revert to prior calculation formula to capture/require increased R&D expenditures or commercialization activity for incentive eligibility.

Program Implementation

A variety of programs will also build capacity around specific areas of focus.

Program Implementation Options for Collaboration
Explore opportunities for research centers of excellence. • Address funding match barriers at smaller public and private institutions. • Consider forming a short-term work group (industry, government and higher education) to identify what it takes to win such a center (i.e. CTSA and NIST manufacturing centers) and where capacity building is necessary to win such a center. • Manufacturing research centers etc. can be significant economic development projects.
Establish a government-university-industry research roundtable. • Form at Commonwealth level to guide further topics and collaboration. A similar construct exists nationally via the National Academies of Science, Engineering and Medicine. NASEM's **GUIRR** convenes to discuss emerging technologies, for example 5G. • Consider forming a standing "panel of independent experts" to convene semiannually to discuss relevant topics including emerging technologies, relative policy development. • A first focus could be determining scope for a short-term "pilot" public private partnership opportunity around research, development and commercialization in one or more area of focus. For example, Mid-Atlantic collaborative around the agricultural and environmental technologies. Use the NC/VA collaboration around the **2019 AgBio conference** as a starting point. • Engage relevant partners and professional associations.
Enhance entrepreneurial support at the Commonwealth's higher education institutions. • While not exclusive to specific areas of focus, input from stakeholders often indicated the need to shift higher education curricula and philosophy to be more entrepreneurial-minded. In other words, encouraging entrepreneurial activities for both students and faculty. • Outreach to student base. Educating students via various platforms will help drive transformation and cultural mindset shift across the institutions. • Educate faculty. Consider a statewide training platform, statewide marketing of successes, statewide iCAP/**iCorps**. • At the institutional level, incorporate into tenure process and faculty work plans encouraging spin out activity and/or industry collaboration.

Funding

Venture capital funding is another component of capacity building. The steps provided below aim to increase funding from the private sector.

Funding Options for Collaboration

For ventures within areas of focus, consider using state funds to match angel funds up to a certain percentage. This can be grant based or via other means.

- Variations of this approach exist across the nation as well as from New Zealand and Israel.
- More information about state examples is at Angel Capital Association.
- One of the concepts outlined in the above link calls for a state facilitated venture capital fund. Consider forming a work group to explore this concept.
- Links to what competitive states are doing include Ohio Capital Fund, Venture Michigan, and the Florida Opportunity Fund. Ohio Innovation Fund specifies areas of focus.

Attract a venture capital representative from a prime venture capital location to have a presence in Virginia.

- For example, Ohio incentivized a major venture capital firm out of Silicon Valley to locate an employee in Ohio to support activity there such as via the Ohio Innovation Fund. Israel has done something similar successfully.

Implement a venture capital "shopping spree" as part of a statewide proof of concept program.

- For proof of concept program, include a "venture capital shopping spree" activity as part of the process.
- For example, the Virginia Innovation Partnership held an event at the United States Patent Office engaging federal and venture capital funders around specific opportunities to promote follow on funding.

Promote and facilitate regional venture capital connections to address regional mismatch challenges.

- Encourage connections between regions with strong sector activity and those with strong funders of those same sectors to address regional mismatch challenges.
- For example, connect life sciences early stage companies in one region with appropriate venture capital and angel investors in another.

TALENT DEVELOPMENT

Stakeholders expressed the importance of ensuring a talent pipeline to support the growth of the Roadmap's focus areas. Input ranged from steps to take at the community college level to connection with statewide initiatives underway.

Talent Development Options for Collaboration

Alignment with other state level efforts.

- For community college students participating in internships that support research activities at four-year institution, work to ensure alignment of learning outcomes with curriculum of degree.
- Consider broadening internship pilot program to include the Roadmap's areas of focus.
- Work to ensure various state-level workforce development programs support the Roadmap's areas of focus.

Talent Development Options for Collaboration
Encourage public institutions to develop industry partnerships to consult on curriculum development and utilize adjunct faculty with current industry experience in those areas of focus to help keep curriculum current. • This could include certificates and training programs. • This could include developing an entrepreneurship curriculum. • This could include industry consultation on key recruitment efforts.

INDUSTRY ENGAGEMENT

From 2010 to 2016, industry-funded research and development increased nationally by 40%. During that same time, Virginia saw a decline by 19% (Source: NSF Science and Engineering State Profiles). A multi-pronged approach is necessary to engage industry collaboration around research, development and commercialization.

Industry Engagement Options for Collaboration
Foster industry-led talent development initiatives in conjunction with higher education. • Encourage the private sector to offer industry days, capstones, internships, 5th year masters - sector-specific or regionally focused outreach. • Work with relevant stakeholders to develop or share templates or standardized processes for use as requested.
Explore and encourage use of Other Transactions (OTs) within each focus area. • OTAs are hybrid transaction agreements that make it easier for the Federal government to engage with the private sector and allow for cost sharing. • For more information about OTAs, refer to OT Guide, OT Guidebook and OTA Overview.
Develop a protocol to facilitate industry connections in real ways and on a routine basis: state level, regional and institutional level interfaces. • Consider inclusion of any applicable institutional research and development faculty or representatives at economic development activities where there are research, development or commercialization needs or potential from industry.
Encourage institutions to allocate a percentage of faculty workweek to engage with industry. • Incorporate into faculty work plans. • Refer to UVA's Link Lab faculty as an example – faculty can allocate up to 6 hours per week to consult with the private sector.

R&D AWARENESS/MARKETING/ADVOCACY

Generally, stakeholders expressed the need for more coordinated marketing, perhaps at the state level, to highlight research, development and commercialization successes to raise awareness and generate interest for additional, future collaboration and support.

R&D Awareness/Marketing/Advocacy Options for Collaboration
Produce and deploy statewide marketing plan and success stories as part of routine/consistent marketing effort by a designated state entity. • A frequently referenced best in class model is Georgia's Research Alliance. • Provide dedicated resources for an ongoing marketing initiative. • Align with research inventory where appropriate.
Develop a state-level advocacy strategy to engage national, high profile leaders in each sector with ties to Virginia who will serve as advocates for research, development and commercialization efforts in the Commonwealth. • Determine appropriate state entity lead for this effort. • Identify and engage potential high profile advocates (industry, venture capital, federal research entities, etc.). • Advocacy and any marketing strategies developed should be complimentary. • Provide dedicated resources for advocacy strategy development and implementation.
Facilitate and/or encourage regional and sector based symposia, technology showcases (state led), conferences or subsets of state associations to connect players over time organically. • For example, a regional chapter of a state-level industry association to build regional relationships between various assets and entities.