Commonwealth Research and Technology (R&T) Strategic Roadmap

November 1, 2011

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Executive Summary

Innovation is essential to success and even more critical in times of constrained resources. Innovation is imperative for firms seeking a competitive advantage, for universities producing talented members of the workforce and world-class research, and for state and local governments cultivating environments that stimulate entrepreneurship and technology development. It requires smart investments in research, commercialization, and the infrastructure and environment that support strategically important industry sectors and technologies.

Virginia is often looked to as a leader in innovation. The Commonwealth's public higher education system is often cited as among the best in the nation. CNBC and Forbes.com have ranked Virginia as the top state for business. Virginia's continued economic leadership requires maintaining investment in research and innovation.

Unfortunately, Virginia lags behind other states according to accepted innovation indicators. The 2010 State New Economy Index, for example, ranked Virginia #21 in industry investment in research and development, and #25 in patents[1]. In the National Science Foundation (NSF)'s annual reporting of academic R&D expenditures, Virginia ranked #15 among all states in 2009.[2] A 2007 report by SRI International, prepared for the Virginia Economic Development Partnership (VEDP), indicated that in 2005 Virginia ranked second to last among its peer states for academic R&D expenditures per capita.[3] As of 2009, this ranking was unchanged. Seed-stage investments also lag; in 2010, Virginia had 29 seed-stage investments compared to 99 in Maryland and 263 in Massachusetts.[4]

Each year the members of Virginia's General Assembly are presented with funding requests for initiatives designed to support growth in specific industries and research areas. While sponsors of the initiatives argue that their requests are critical investments in the future of the Commonwealth, legislators can find it difficult to separate the wheat from the chaff during the brief but hectic sessions that include thousands of legislative and budget-related proposals.

During its 2011 Session, through HB2324, the General Assembly directed the Center for Innovative Technology (CIT) to create a Commonwealth Research and Technology (R&T) Strategic Roadmap to help guide legislators in their funding decisions. In accordance with Code of Virginia Sections 2.2-2221.2 D and 2.2-2221 (18), CIT respectfully submits the Roadmap. The results outlined in this report are the

[1] The Information Technology & Innovation Foundation and Kauffman Foundation, *The 2010 State New Economy Index*, 2010.
[2] National Science Foundation, *Academic R&D Expenditures FY2009*, 2009.
[3] SRI International, *Assessing the Technology Industry Potential of the Commonwealth of Virginia*, November – December 2007.
[4] PricewaterhouseCoopers and National Venture Capital Association, *MoneyTree™ Report*, Q3 2006 – Q2 2011, 20 September 2011, www.pwcmoneytree.com.

product of a close collaboration from a team that included Virginia's private sector – led by the Commonwealth's ten regional technology councils, its colleges and universities, as well as federal labs and other research entities. A broad range of senior executives from industry, academia, federal laboratories, other research organizations, economic development offices, and the Research and Technology Investment Advisory Committee (RTIAC) contributed to the Roadmap. Additionally, CIT acknowledges the important contributions of the Secretariats of Technology, Education, and Commerce and Trade; VEDP; Virginia Tech; and Chmura Economics & Analytics in developing this Roadmap.

This report identifies industry and research areas worthy of economic development and institutional focus and offers a framework for aligning key industry sectors within the state. It is also intended as a guide for investing funds allocated through initiatives such as the Commonwealth Research Commercialization Fund (CRCF).

Legislation calls for the Roadmap to be submitted by November 1, 2011, and to be updated at least every three years. Because the CRCF program is tied to the review of the Roadmap, CIT is submitting this report regarding industry opportunities for investment on an accelerated schedule.

Opportunities outlined in this report are the result of a rigorous and iterative assessment process that included examination of Virginia's industry and research strengths from multiple perspectives. These strengths were compared to national and global initiatives and priorities to ensure relevance and direct market applicability. These opportunities not only represent high priority industries and research disciplines that promise favorable out-year growth, but variations thereof as well.

The first phase of the Roadmap has identified the following sectors for investment in the Commonwealth, including research and technologies eligible for CRCF funding in the October 2011 solicitation:

- **Advanced Manufacturing**, with particular interest in semiconductors, unmanned vehicles, robotics, remote monitoring and sensing, surface engineering, chemicals, advanced materials, and nanotechnology – especially nanoelectronics and nanomedicine
- **Aerospace**, with particular interest in launch vehicles and commercial space flight
- **Communications,** with particular interest in broadband and wireless telecommunications
- **Cyber Security**, with particular interest in data center security, network and perimeter security, authorization and authentication technologies, disaster recovery and continuity of operations technologies, and application and device security
- **Energy**, with particular interest in smart grid, green construction including retrofitting, nuclear plant safety and support, wind technologies, biofuels, and waste-to-energy applications
- **Environment,** with particular interest in marine science and water and air quality monitoring and control
- **Information Technology**, with particular interest in software and application development and data management, analytics, and storage

- **Life Sciences**, with particular interest in biotechnology, biomedicine, health IT, bioinformatics, biomarkers, biometrics, personalized medicine, remote care delivery, drug discovery, and computer-assisted drug design
- **Modeling and Simulation**, with particular interest in energy, transportation, healthcare, and homeland security and defense applications
- **Nuclear Physics**, with particular interest in advanced manufacturing, energy, environment, life sciences, information technology applications, and a 4th generation light source
- **Transportation**, with particular interest in vehicle telematics, vehicle and driver performance monitoring, and intelligent transportation systems

Properly structured intellectual property (IP) agreements help foster innovation; as called for in legislation, IP will be addressed as part of any CRCF award.

Investments targeted at the intersection of industry capabilities and direction, research strengths, and economic development can create a multiplier effect that increases the benefit of the CRCF and other industry/research growth initiatives.

Two of Virginia's strongest and most promising sectors not only run across multiple regions but are also enabling technologies. The Information Technology and Modeling and Simulation sectors facilitate development in Transportation, National Security, Healthcare, Advanced Materials and Manufacturing, Energy, and Environment. Similar synergies across regions and technologies can be found in Life Sciences, Aerospace, and other sectors and subsectors. Likewise, investments in Cyber Security and Remote Monitoring and Sensing could have impact across multiple sectors and regions. Identifying and funding these high-impact technologies will have widespread benefit to individual regions and to the Commonwealth as a whole.

Given these synergies and past tendencies to function independently of one another, opportunities exist for the Commonwealth and regions to benefit from sharing complementary goals, expertise and resources. By showcasing the Commonwealth's priorities and indicating areas of particular strength or capabilities, regions will be able to take advantage of others' accomplishments, thus improving Virginia's standing as a whole. For example, sensing and measurement technologies were identified as a priority in Hampton Roads, Region 2000, and Roanoke-Blacksburg. This technology, furthermore, spans the Communications, Energy, Aerospace, Transportation, and Defense industries. Investments in this industry, therefore, would have widespread benefit across the Commonwealth.

Virginia's strengths and priorities help establish its competitive advantage. Capabilities in target sectors have been cultivated for years, as demonstrated in such reports as 2003 Assessment of Virginia's College and University Research Programs by then-Governor Warner's Research Panel, the 2007 SRI/VEDP Assessment of Technology Industry Potential in the Commonwealth, and the 2007 report of the Virginia Research and Technology Advisory Commission (VRTAC), Collaborative Research and Development Strategies for the Commonwealth of Virginia.

Not only do its strong and most promising capabilities align with national priorities, but the effects extend internationally as well. Virginia boasts a close proximity to the federal government; this and a multitude of other factors, including its ports and airports, skilled and highly educated workforce, renowned educational system, and pro-business climate, strengthen its competitive advantage. The iterative nature of the R&T Roadmap plots a wise course in this rapidly changing environment: to regularly review and, as needed, revise Virginia's strategic technology direction and investments. The next phase of the Roadmap also will be accelerated and is scheduled to be delivered in May 2012. Phase II will:

- Refine where efforts should be focused, including basic and applied research opportunities
- Develop a process for cataloging research endeavors
- Review and potentially revise the IP policy for CRCF awards
- Address capital construction needs when timing aligns with work by the State Council of Higher Education for Virginia (SCHEV) and the academic community

The Commonwealth Research and Technology Roadmap is the first state-wide community, university, and industry technology tool developed by stakeholders for the purpose of planning, investing, and communicating the future of technology development. This strategic process will enable more efficient resource utilization and maximize public and private return on investment. In addition to improving efficiencies in industry development, this initiative improves global competitiveness by accelerating the rate of new technology development and production.

Introduction

The Commonwealth Research and Technology (R&T) Strategic Roadmap was established by HB2324 during the 2011 Session of the General Assembly as part of Governor McDonnell's "Opportunity at Work" initiative to bolster innovation in emerging technologies in the Commonwealth and spearheaded in the General Assembly by Delegates Scott Lingamfelter and Joe May, and Senators Mark Herring and Stephen Newman. It evolved from previous initiatives, including 2009 legislation calling for a comprehensive research and development strategic roadmap and the Governor's Commission on Higher Education Reform, Investment and Innovation that charged the Innovation Entrepreneurship Investment Authority (IEIA) to advance research and commercialization and that supported IEIA in proceeding with the Roadmap. In accord with Code of Virginia Section 2.2-2221.2 D, CIT submits the R&T Roadmap – a comprehensive framework the Commonwealth will use to identify research areas worthy of economic development and institutional focus. The Roadmap also supports Code of Virginia Section 2.2-2221 (18).

The R&T Roadmap pinpoints and aligns key industry sectors within the state that merit investment by conducting assessments of the Commonwealth's strengths and commercial opportunities. The methodology incorporates iterative assessments of key criteria from multiple perspectives, using industry priorities and opportunities as the foundation. This approach provides a critical evaluation of regional priorities, existing and projected capabilities, economic development initiatives, and key research strengths in Virginia's universities and labs. Opportunities are identified not only on capability, but also on an evaluation of the external climate that includes national and global priorities.

The foundation of the Roadmap's industry analysis – the Commonwealth Innovation Index – was built by hundreds of industry leaders, researchers, and economic developers who assisted in developing profiles of strengths and priorities in every region of the Commonwealth. Subsequent stages of the Roadmap will refine that list of profiles through a series of assessments (outlined in later sections of this report), thereby defining investment priorities for industry. Mapping those priorities to research strengths in Virginia's public and private universities and research labs resulted in the final list of opportunities presented in this report.

The Roadmap highlights the commercially promising sectors that will drive economic growth in the Commonwealth. Legislators and other elected officials can use the information from the Roadmap to make informed investment decisions in research, technology, and economic development initiatives. In areas where Virginia is already strong, these investments can help robust sectors excel. Where Virginia lags, but where market opportunities exist, investments will strengthen these sectors, making Virginia even more competitive. Beyond this, the Roadmap will also help inform and align organizations across the state, including public and private universities.

Legislation calls for the Roadmap to be submitted to the General Assembly on or before November 1, 2011; this submission is the first of a multi-phase project, including updates at least every three years. Subsequent phases will include recommendations to the Six-Year Capital Outlay Plan Advisory

Committee and maintenance of an online inventory of the Commonwealth's current R&D endeavors in both the public and private sectors that can be used by researchers, industry, economic development professionals, elected officials, and others to facilitate awareness of and access to R&D and commercialization capabilities throughout the Commonwealth.

Findings from the Roadmap identify industry sectors and disciplines eligible for awards from the Commonwealth Research Commercialization Fund (CRCF), which was allocated $6 million for FY2012. Research and technology areas eligible to receive funding for the CRCF are identified in the Roadmap and awards from the Fund may only be made to those applications that further the goals set forth in the Roadmap.

Key Industries

The assessment of critical statewide industry sectors and subsectors is the first step in identifying research areas worthy of institutional focus and Commonwealth investment. This assessment must consider well-defined regional priorities, statewide economic development initiatives, and industry strengths in light of the external climate and Virginia capabilities. The assessment also takes into account the potential for growth, commercialization, and job creation of various industries and research areas.

The Roadmap uses three separate perspectives to ensure a comprehensive view of the technology landscape – the Commonwealth Innovation Index, economic development priorities, and data-driven analysis of leading and lagging indicators. The iterative methodology uses a bottom-up (regional strategies) assessment of industry strengths and opportunities that is validated and refined by statewide economic development priorities. The resulting industry sectors and subsectors are then evaluated through a top-down (statistics-based) review designed to identify favorable industry climate and capability metrics. Although the top-down portion of this industry assessment is based on a current snapshot of Virginia's workforce and business base, CIT's Innovation Index is a dynamic and ongoing initiative. Priorities and opportunities continue to be assessed and cultivated in every region of the Commonwealth. Updates to the Roadmap will refine the priorities established in this iteration.

Not surprisingly, there is no standard set of industry or subsector names and definitions; differences exist among various studies, between the public and private sectors, and between industry and academia. Additionally, significant discrepancies exist between the terms used for categories by the North American Industry Classification System (NAICS) and those commonly used by innovation industries. We accept these discrepancies and have made every effort to accommodate industry terminology that is reflective of real-world planning initiatives.

Conclusions drawn from this collection of data components have been used to assess industry and research areas that hold the best promise for growth and return on the Commonwealth's investment. The findings of this process support investment strategies in areas where there exists:

1. Favorable external climate and strong Virginia capabilities
2. Strong Virginia capabilities and less favorable external climate
3. Favorable external climate and weaker Virginia capabilities

Key industry sectors and subsectors have been identified, evaluated, and categorized into one of these investment strategies – detailed later in this section.

A fourth category – less favorable external climate and weaker Virginia capability – also resulted from this process. Because this study aims to identify industries and research areas that merit investment from the Commonwealth, this report will not address the weakest candidates.

Subsequent phases of the Roadmap will refine these results, enabling even more targeted investment. On a high level, in this phase, and solely from the Industry section of this report, industry and community recommendations support investing in the following areas: Aerospace, Aviation, Communications, Energy, Environment, Information Technology, Life Sciences, Modeling and Simulation, National Security, and Transportation.

Innovation Index – Regional Priorities

The Commonwealth's Innovation Index was created at the request of Virginia's General Assembly through Senate Joint Resolution 126 during the 2008 Session. The intent of the unanimously passed Joint Resolution – and of the resulting program – was to assist communities in identifying key technology strengths and priorities, as well as identifying and building an accompanying infrastructure that would support innovation-based economies. This infrastructure is intended to be a foundation for local and statewide economic development efforts that foster the formation, retention, and expansion of regional technology-based opportunities, including: expanded entrepreneurship, increased availability of seed-stage funding for start-ups, and applied research leading to commercialization of intellectual property in the Commonwealth.

An essential and unique element of the Innovation Index is that it provides a community-driven or "bottom-up" perspective on economic priorities. In developing the Index, CIT engaged with Virginia's ten regional technology councils and statewide technology community to identify each region's current and future strategic technology priorities. Beyond uncovering local opportunities, the Innovation Index also cataloged each region's challenges, enabling organizations, institutions, and essential assets.

The Innovation Index is an on-going CIT initiative. Focus group meetings, which became a key method for gathering regional data, were held to begin identifying local and statewide strengths and priorities; however, these meetings were not intended to identify all opportunities for innovation and economic development in the targeted industries. They were the beginning of a process that will evolve, expand, and shift focus and, ultimately, may lead to additional opportunities. Subsequent phases of the Innovation Index process will focus on identifying and including these developments so that strategies and investments can be revised if regions' needs and priorities change.

Regional Industry Priorities

A complete table of regional industry priorities and niche opportunities can be found in Appendix C.

Virginia Economic Development Partnership (VEDP) – Economic Development Priorities

VEDP's mission is to cultivate new business investment, foster international trade growth, and encourage the expansion of existing industries, primarily through job creation and investment.

VEDP Business Development Markets

VEDP directs its recruitment and outreach resources towards markets it expects will produce strong gains in employment, higher wages, and new capital investment. It works with local partners to identify broad vertical markets. By then mapping these markets to regional assets, VEDP can best meet the needs of the business clients.

VEDP's key vertical markets include:

- **Advanced Manufacturing and Logistics**, including plastics and polymers, advanced materials, food processing, chemicals and fibers, aerospace, automotive, and logistics
- **Security and Services**, including the federal security agencies and providers, information technology, cyber security, professional and business services, finance and insurance, corporate headquarters, and management operations
- **Science and Research**, focusing mainly on R&D, clean and alternative energy, life sciences, nanotechnology, medical applications and devices, other emerging technologies, and healthcare services

Complementing this market focus, VEDP has developed a series of initiatives to meet its mission goals in strategic areas. These initiatives include:

- The **Distributed Services Initiative** helps communities/regions generate a value case for moving segments of the information technology industry from high-cost locations to areas where operating costs are lower. This initiate meets local workforce development goals and provides skills development in regions needing economic diversification.
- The **Offshore Wind Energy Initiative** helps position Virginia for significant manufacturing and supply chain operations should offshore wind become a viable energy generation option.
- Generating support for the **Tobacco Commission R&D Centers** is crucial to development in Southern and Southwestern Virginia. Through a strategic partnership, VEDP implemented a Scientific and Technical Review Panel as part of the vetting process for companies applying for the Tobacco Indemnification and Community Revitalization Endowment (TICRE)'s R&D grant program funds. Since VEDP assembled the Panel, four companies have been awarded funding through the Tobacco Commission.
- The **Life Sciences Initiative** aims to identify key research themes that will form the core of Virginia's Life Sciences market strategy. VEDP is leading this effort and has engaged with Virginia

research universities and the Administration. Although this process remains under way, leading strategic tracks include:
    - Bioinformatics and Medical Informatics
    - Point-of-Care Diagnostics
    - Drug Discovery and Delivery
- The **Federal Strategic Initiative** whereby VEDP works with various federal agencies to identify strategic and operational needs of the U.S. government.
- The **Strategic Properties Initiative** is aimed at trying to better position some 8,000+ new industrial acres being developed by various regional entities, many of which are in rural areas. VEDP will work closely with the regions to help identify appropriate business markets for these properties.

Virginia's Economic Development Priorities and Industry Strengths

VEDP also uses business and employment statistics to identify the Commonwealth's primary industry sectors. Those industries and subsectors include the following:

- **Aerospace**: Virginia is home to 159 aerospace companies. The largest subsectors for the industry are aerospace technology and aerospace equipment.
- **Automotive**: The automotive industry accounts for 3% of Virginia's total of 6,200 manufacturing establishments. Virginia is home to 173 automotive companies.
- **Plastics and Advanced Materials**: More than 200 plastics companies have located in the Commonwealth, employing more than 24,800 Virginians.
- **Corporate Headquarters**: Virginia's pro-business climate, global access, and talented workforce combine to make the ideal location for corporate headquarters. Virginia is home to more than 70 headquarters that earn at least $600 million in revenue each year.
- **Energy**: Virginia is home to 384 energy companies. The top subsectors for the energy industry are traditional power generation and fossil fuel sources.
- **Food Processing**: In 2008, Virginia's food processing industry employed more than 34,700 people, or 12.7% of Virginia's total manufacturing employment.
- **Global Logistics**: Virginia's highway and rail infrastructure makes the Commonwealth an ideal location for distribution to Eastern U.S. and Midwest markets.
- **Life Sciences**: In 2008, the life sciences industry accounted for more than 16,200 jobs in over 700 firms in Virginia.
- **Information Technology**: With more than 285,000 high-technology jobs in Virginia in 2008, Virginia has the highest percentage of technology workers in the country and is ranked 5th in total high-technology employment.
- **Modeling and Simulation**: Virginia has 190 companies applying modeling and simulation technology to defense, health care, aerospace, transportation, and entertainment industries.
- **Wood Products**: This sector represents Virginia's largest number of manufacturing establishments. The top three subsectors for wood products are household and institutional

furniture and kitchen cabinet manufacturing, other wood product manufacturing, and sawmill and wood preservation.

Chmura Industry Analysis

Success in business requires a keen understanding of the current and future marketplace, knowing the competition, and maintaining a workforce with cutting-edge skills and innovation. The same factors apply to the Commonwealth as it competes for leadership in industries that will define the global economy. Achieving that success begins with a deep understanding of Virginia's business and labor base. CIT contracted with Chmura Economics & Analytics to identify the strongest and most research-intensive industries in Virginia that also have the most growth potential. The resulting study provided a statistical foundation for assessing the strength of the Commonwealth's existing industry and workforce base.

Background

Chmura Economics & Analytics identified and evaluated research-intensive industries in Virginia based on current and historical economic data sets:

- Data on past industry and wage growth and industry competitiveness from the Quarterly Census of Employment and Wages (QCEW) (2010).
- Data on export growth, value added, and industry multipliers (2009) from IMPLAN Pro software, which allows economists to perform input-output analysis on regional economies.
- Establishment and sales data from the National Establishment Time-Series (NETS) database (2009).
- Research and development data for national and Virginia universities, from the National Science Foundation (NSF) (2004-2009).
- Federal contracts data, from U.S. General Services Administration (GSA)'s Federal Procurement database (2010).
- Patent data for industries and universities from the U.S. Patent and Trademark Office (2010).
- Data on venture capital spending from Thomson Reuters (2010).

The federal NAICS classifies firms into industries for statistical purposes based on the goods or services they create. The industries analyzed in this report are based on NAICS codes at the four-digit level. This study selected and evaluated 64 four-digit NAICS level industries based on requirements of HB2324, regional input to the Commonwealth Innovation Index, and the industry priorities of the VEDP.

The 64 industries are classified in the following ten major sectors:

- Advanced Manufacturing
- Aerospace
- Aviation

- Communications
- Energy
- Environment
- Information Technology
- Life Sciences
- National Security
- Transportation

Summary of Findings

Chmura developed a Climate-Capability Matrix (Figure 1) to help identify industries meriting state support in research and development. The Climate-Capability Matrix provides a comprehensive evaluation of the 64 industries; for each industry, the matrix shows an industry's performance with respect to the external climate and its Virginia capability.

- The upper-right quadrant of the matrix includes industries that enjoy a favorable external climate and also exhibit strong capabilities in Virginia. Industries – many of which are from the Information Technology sector – that fall into this quadrant are poised for growth, and R&D funding provided to these industries that have shown above average success in both filters would likely have the highest success.
- The lower-right quadrant contains industries with strong Virginia capabilities, but with a less favorable external climate. Investment in these industries may help solidify Virginia's leadership roles in these fields.
- In contrast, the upper-left quadrant reflects a favorable climate in the nation but lower capabilities for Virginia's industries. Providing funding to industries that fall into this category – many of which are Advanced Manufacturing – would help to cultivate those businesses for long-term growth and allow them to catch up with industry leaders around the nation; long-term rewards may be significant if these sectors become future growth industries for the Commonwealth.
- The lower-left quadrant reflects both an unfavorable external climate and weak capabilities in Virginia. As mentioned above, these industries are not discussed further.

The external climate index measures an industry's national and global strength based on:

- Projected output growth
- Historical export growth
- R&D spending as a percentage of total sales
- Venture capital investment
- Industry output multipliers

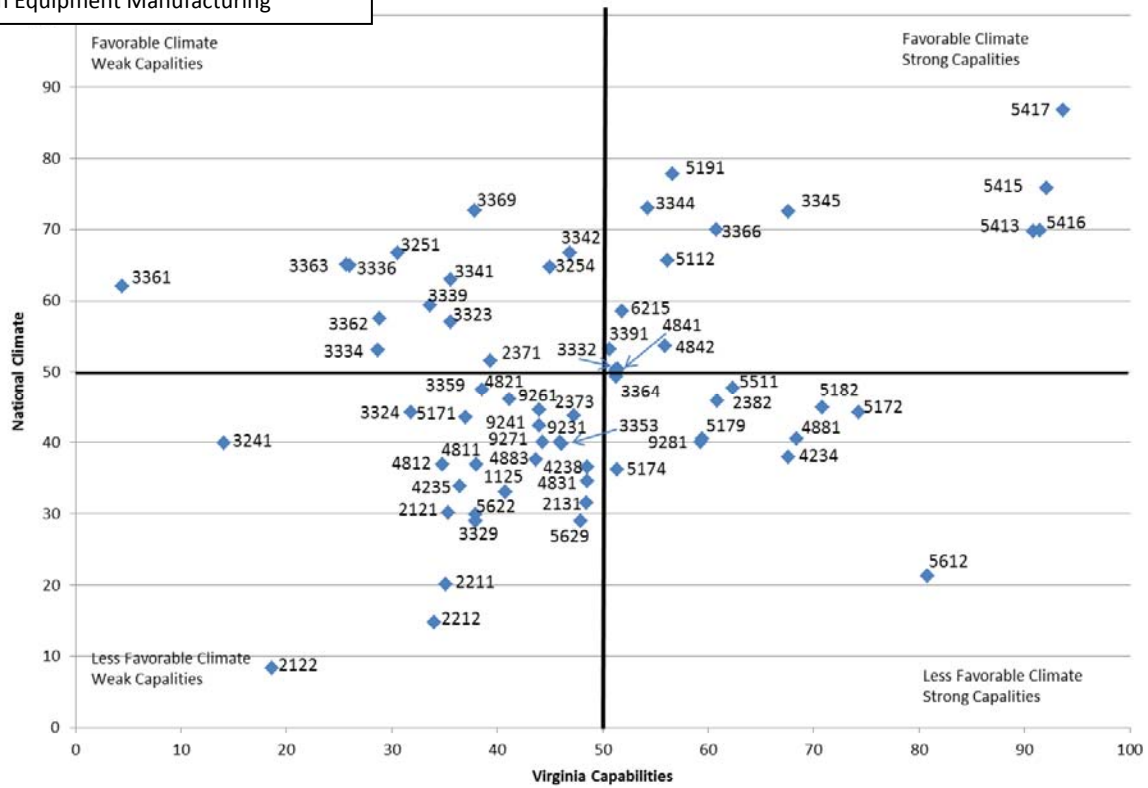
The Virginia capability index measures an industry's strength in Virginia based on:

- Location quotient
- Employment growth
- Relative wages and wage growth
- Federal R&D grants
- Number of patents issued
- Industry output multipliers

Table 1.2: Favorable U.S. Climate and Low Virginia Capability

2371	Utility System Construction
3251	Basic Chemical Manufacturing
3254	Pharmaceutical and Medicine Manufacturing
3323	Architectural and Structural Metals Manufacturing
3334	HVAC and Commercial Refrigeration Equipment Mfg
3336	Engine, Turbine, and Power Transmission Equipment Manufacturing
3339	Other General Purpose Machinery Manufacturing
3341	Computer and Peripheral Equipment Manufacturing
3342	Communications Equipment Manufacturing
3361	Motor Vehicle Manufacturing
3362	Motor Vehicle Body and Trailer Manufacturing
3363	Motor Vehicle Parts Manufacturing
3369	Other Transportation Equipment Manufacturing

Figure 1:
Climate-Capability Matrix of Virginia Industries



Chmura Economics & Analytics, 2011

Favorable U.S. Climate and High Virginia Capability

3332	Industrial Machinery Manufacturing
3344	Semiconductor and Other Electronic Component Manufacturing
3345	Navigational, Measuring, Electromedical, and Control Instruments Mfg
3366	Ship and Boat Building
3391	Medical Equipment and Supplies Mfg
4841	General Freight Trucking
4842	Specialized Freight Trucking
5112	Software Publishers
5191	Internet Publishing and Broadcasting (NAICS 2002)
5413	Architectural, Engineering, and Related Services
5415	Computer Systems Design and Related Services
5416	Management, Scientific & Technical Consulting Services
5417	Scientific R&D Services
6215	Medical and Diagnostic Laboratories

Less Favorable U.S. Climate and High Virginia Capability

2382	Building Equipment Contractors
3364	Aerospace Product and Parts Manufacturing
4234	Professional and Commercial Equipment and Supplies Merchant Wholesalers
4881	Support Activities for Air Transportation
5172	Wireless Telecommunications Carriers (except Satellite)
5174	Satellite Telecommunications
5179	Other Telecommunications
5182	Data Processing, Hosting, and Related Services
5511	Management of Companies and Enterprises
5612	Facilities Support Services
9281	National Security and International Affairs

External Climate

The external climate index measures an industry's national and global strength based on factors such as projected output growth, R&D spending as a percentage of total sales, venture capital investment, and industry output multipliers. The Information Technology sector had the highest external climate index, followed by Advanced Manufacturing, Transportation, and Life Sciences. Highlights of the external climate index include the following:

- Information Technology, Life Sciences, Advanced Manufacturing, and Energy were the recipients of large venture capital investments in 2010, indicating confidence that these sectors have momentum for the future.
- The Information Technology sector, along with the Environment sector, offers opportunities to achieve above-average growth in both output and employment from 2008 to 2018.
- The Aviation, Transportation, Advanced Manufacturing, and Energy sectors experienced double-digit annual growth in exports from 2001 to 2009.
- At the national level, the Aerospace, Advanced Manufacturing, and Life Sciences sectors invest relatively large amounts in R&D, signaling high innovation potential.

Virginia Capabilities

The Virginia capabilities index measures how well an industry is poised to grow based on its current economic performance, innovative potential, and value add. The Information Technology and Environment sectors had the highest score on the Virginia capabilities index due to their high wages, high employment growth, and strong ability to attract federal R&D funding. The index also shows the following:

- The Communications and National Security sectors also had relatively high Virginia capabilities index scores.
- The Environment sector had both the largest workforce and the fastest employment growth from 2002 to 2010 among the ten innovation sectors, followed by Information Technology.
- Above-average wages were found in four sectors – Aerospace, Communications, Information Technology, and National Security.
- Among the innovation sectors, Information Technology received the most patents over the past five years, followed by National Security and Advanced Manufacturing. Industry patents indicate that R&D spending has led to inventions that are worthy of patent protection.
- In FY2010, Virginia received 10.8% of all federal procurement contract awards, highest among all states. Of that, $4.5 billion was awarded to Virginia firms for R&D, placing Virginia third in the nation.

Chmura Conclusion

Virginia's future position as a leader in research and innovation will be dependent on the ability of entrepreneurs and mature businesses to turn innovations into marketable products. State investment in selected industries within the private sector, academia, and elsewhere in the research and commercialization community, will also play a significant role in securing Virginia's leadership in the nation. Virginia possesses many capabilities that place it in a strong position when compared with other states.

This study creates a process that allows Virginia to identify strong industries and to track their performances over time. The Climate-Capability Matrix not only can help identify industries to invest in, but updating the performance indicators in the matrix can also enable the Commonwealth to track the progress of its investment.

Industry Opportunities

With consideration of the data, information, and discussion presented in the previous sections, industry subsectors have been assigned to one of three investment environments. These assignments represent priorities established solely on industry criteria and must be balanced with the Commonwealth's research strengths and priorities.

Favorable External Climate and High Virginia Capability

- **Advanced Manufacturing**, including semiconductors, robotics, wireless sensors, shipbuilding, surface engineering, and unmanned vehicles
- **Cyber Security,** including data center security, network and perimeter security, biometrics, authorization and authentication technologies, disaster recovery and continuity of operations technologies, and application and device security
- **Energy**, including smart grid, energy data analytics, biomass, and green construction
- **Environment**, including resource conservation, marine science, and oceanographic R&D
- **Information Technology**, including computer equipment, software and application development, and data analytics and storage
- **Life Sciences**, including biotech, biomed, cancer treatment, health IT, bioinformatics, personalized medicine, biometrics, and remote care delivery
- **Modeling and Simulation**, including transportation, healthcare, business process optimization, and homeland security and defense

Less Favorable External Climate and High Virginia Capability

- **Aerospace**, including satellites, launch vehicles, unmanned vehicles, commercial space flight, and International Space Station and Spaceport support

- **Aviation**, including air transportation and supporting activities for air transportation
- **Communications**, including telecommunications (such as wireless and satellite communications) and cognitive radio
- **Energy**, including nuclear plant safety and support, human factors engineering, power electronics, offshore wind, smart appliances, and electric/hybrid vehicles
- **Life Sciences**, including drug discovery and computer-assisted drug design
- **National Security**, although not typically recognized as stand-alone industry, is the intersection of sectors that are focused on defense and homeland security, including intelligence, cyber security, port security, and biothreats
- **Transportation**, including vehicle telematics and vehicle and driver performance monitoring

Favorable External Climate and Low Virginia Capability

- **Advanced Manufacturing**, including chemicals and motor vehicle manufacturing
- **Communications**, including telecommunication equipment
- **Energy**, including alternative fuels and power generation equipment
- **Life Sciences**, including nuclear medicine, tobacco-based vaccines, and pharmaceuticals

Academia

Background

The Roadmap, in part, is intended to identify common themes among Virginia's research universities with the goal of mapping university capabilities to industry and research organizations' strengths and priorities. This benchmark provides insights into research areas that are the most likely to result in science and technology commercialization. For the purposes of this study, a "research university" is defined as one with more than $5 million in annual R&D expenditures, as reported by NSF for FY2009. Virginia's research universities, by this definition, include: the College of William and Mary (W&M), Eastern Virginia Medical School (EVMS), George Mason University (GMU), Hampton University (HU), James Madison University (JMU), Norfolk State University (NSU), Old Dominion University (ODU), the University of Virginia (U.Va.), Virginia Commonwealth University (VCU), Virginia State University (VSU), and Virginia Tech. Input was also solicited from George Washington University (GWU) on the basis of its research expenditures, and impact on the Commonwealth of its Virginia Science and Technology campus, located in Loudoun County. Based on this approach, 12 universities were engaged, nine which are public and three which are private.

In order to identify and gauge strengths and priorities at of these 12 research universities, each institute was asked to provide a list of research priority areas as set forth in its strategic plan, as well as any additional research areas, or other changes or additions identified since the university's last strategic planning process. NAICS codes were used to correlate university expertise and priority areas to potential areas of commercial impact. Relevant sectors were identified, and technology areas were adapted to an academic context. Each university was then asked to map its research to the adapted list of technology areas, noting areas of specialization. Responses were compiled and analyzed in order to identify common research priority areas.

This review was conducted in parallel with other university planning initiatives, including the Six-Year Plan process, done in conjunction with the State Council of Higher Education for Virginia (SCHEV).

University Strategic Plans

Universities' strategic plans focus on goals and projected outcomes over a five- to six-year period, addressing academic programs, research priorities, and plans for outreach and engagement. Because universities often consider research to be an integral component of the overall academic experience of students, the strategic plans reflect the entire scope of university research, including fields that do not carry an expectation for commercialization, as well as those that do. Through the strategic planning process, a university establishes its commitments, goals, and strategies within local state, national, and

global contexts. In recent years, emphasis has been on university research that lies at the intersection of disciplines. Universities have also built partnerships that allow them to leverage expertise and resources from national laboratories, government, and private industry. These partnerships also allow Virginia's universities to compete for funding that increasingly has been awarded to large-scale interdisciplinary teams rather than individual investigators. Competition to win such awards is usually among university consortia or teams drawn from the strongest institutions across the nation.

University Research Priorities

Collectively, the Commonwealth's research universities place emphasis in the following technology sectors: Energy, Environment, Life Sciences, National Security, and Information Technology. Within these areas, interdisciplinary fields such as bioinformatics, health IT, bioengineering, the nano-bio interface, sustainable design, research related to complex systems, modeling and simulation, health and biosciences, and nanotechnology have been identified as areas of strength. In addition, new opportunities in energy and sustainability, biomedical research, information technology, personal and cyber security, and nanoscience and engineering are strongly reflected in the strategic plans of most universities. A table outlining the research priorities at Virginia's research universities and to which industry sectors these priorities best map can be found in Appendix D. In order to have a more comprehensive view of academic research priorities, detailed information from universities not reflected in the table will be sought for the Phase II report.

Energy and Environment

The national focus on Energy and Environment sectors offers a significant opportunity for the Commonwealth to leverage its strengths in these areas. Federal funding has given university researchers new opportunities to engage in projects such as the modernization of the electrical grid, grid security, energy efficiency, sustainable building and design, and alternative energies, among others. Several Virginia university strategic plans have noted a strategic focus on smart grid technologies, as well as studies of the impact of new energy technologies on water quality, the climate, and environmental policy. Energy sources are also a strong research area, with investigators working on photovoltaic technologies, biofuels, and wind energy. Along with alternative transportation fuels research (from algae or non-food crops), the number of nuclear programs being established at Virginia universities is increasing. As a result, more than 100 technologies related to energy and the environment are currently available for licensing from Virginia universities, an indicator of the level of current faculty involvement in the creation of intellectual property in this area.

Life Sciences

Within the Life Sciences industry – specifically the medical and biotechnology subsectors – several universities noted research related to public health and aging. Immunology, infectious disease, cardiovascular disease, and cancer research also represented cross-cutting research priorities. Research in personalized medicine, neuroscience, biomarkers, medical imaging, diagnostics, and integration of

social media into patient care were also identified. Based on foundational strengths in Information Technology, as well as a national focus on health sciences and health IT, additional opportunities exist in the area of remote patient monitoring and care delivery. Medical device development as a potential or emerging area of strength was noted by several schools. Finally, the Commonwealth's commitment to biomedical research is led by the U.Va., VCU, and EVMS, each of which have firmly established medical schools and a strong research presence, and the newly established Virginia Tech Carillion Research Institute (VTCRI). These Virginia assets will address some of the major health issues of the present and the future.

Based on the strength of existing programs and the level of new investment, Life Sciences are poised to create the breakthroughs and innovation that leads to technology transfer. At present, more than 300 technologies are available for licensing from Virginia universities.

Information Technology

The continued support and development of information-related technologies will be critical to meet the grand challenges of complex systems and to support computationally-intensive research. In the Information Technology area, the majority of universities noted faculty and research expertise in modeling and simulation applications related to business, biotechnology, medical sciences, cyber security and critical infrastructure protection, transportation, and visualization. Most universities also noted computer software development, bioinformatics, data analytics, and cloud computing as focus areas.

Nanotechnology, Materials, and Chemistry

The majority of universities conduct research in nanomaterials and/or nanoscale electronics. Expertise in this area is varied, ranging from nanoscale fabrication for medical applications to the nano-bio interface. Research opportunities exist to leverage nanotechnology and environmental expertise, focusing on the need to relate a vast array of nanomaterial properties to their potential environmental exposure, biological effects, and ecological consequences. Additional research in this area can be seen in composites, films and coatings, and polymers, for example. More than 40 technologies related to nanotechnology, materials, and chemicals are currently available for licensing from Virginia universities.

Other Research Focus Areas

Other significant cross-cutting areas of research include, but are not limited to, wireless networks, mobile communications, driver monitoring and vehicular applications, remote sensing, and robotics. These are not necessarily stand-alone applications, but enabling technologies and capabilities. Universities also noted that an opportunity exists to leverage expertise in information and education technologies in research areas such as Aerospace, Communications, Transportation, Advanced Manufacturing, Information Technology, and Life Sciences.

Other Research and Development Assets

The Commonwealth of Virginia is home to research and development assets that augment the state's capabilities in research, technology development, and education. For Phase I of the Roadmap, CIT conducted interviews with six R&D institutions: three federal labs – the Thomas Jefferson National Accelerator Facility (Jefferson Lab), NASA Langley Research Center (NASA LaRC), and the Naval Surface Warfare Center Dahlgren Division (NSWCDD, Dahlgren) and three research organizations – the Commonwealth Center for Advanced Manufacturing (CCAM), SRI Shenandoah Valley Center for Advanced Drug Research (SRI SV CADRE), and the National Institute of Aerospace (NIA).

Commonalities Among the Commonwealth's R&D Assets

Many commonalities exist among the research institutes and federal labs of the Commonwealth. All of the organizations emphasize basic research, and many also focus on applied research and technologies that can be transitioned into the field. Likewise, the institutions share an interest in and need for increased industry and/or university interactions. While some organizations already have connections established, all could benefit from strengthening these relationships. A focus on education and outreach sets many of the institutions apart. In particular, NASA LaRC, NIA, and the Jefferson Lab stress the importance of educating the next generation of scientists. Similarly, Dahlgren and the Jefferson Lab allow industry and academia to utilize their facility, resources, experience, and expertise. A common thread among almost all the organizations is the dedication to the development of life-changing technology that will be key to advancing the innovation continuum and economy.

Both a high level of synergy and diversity exists among key industry sectors represented by the research institutes and federal labs. Research is focused in the following areas: Advanced Manufacturing, Aerospace, Aviation, Communications, Energy, Environment, Information Technology, Life Sciences, National Security, and Transportation. The table in Appendix E illustrates the relationship between strategic focus area and industry sector.

Commonwealth Center for Advanced Manufacturing (CCAM)

CCAM is an applied research center, established in May 2010, focusing on advanced manufacturing applications in surface engineering and manufacturing systems. This new Center's research will support an array of technology sectors, including Advanced Manufacturing, Aerospace, Energy, National Security, and Transportation.

CCAM is constructing a state-of-the-art ~60,000 square foot research facility in Prince George County, Virginia, on the Rolls Royce Crosspointe campus; the facility is expected to be operational in August 2012. CCAM bridges the gap between fundamental research typically performed at universities and the manufacturing capability readiness level required by companies to accelerate new advanced

technologies to the factory floor. Structured as a non-profit membership-based institute, CCAM is primarily an industry-directed translation research organization – it helps move fundamental university research to the factory floor. It also brings large industrial firms and their supply chains together to foster collaborative research and structure, thereby leveraging investments and lowering research costs. The members represent advanced technology sectors present in Virginia: Aerospace, Shipbuilding, Defense, and Advanced Manufacturing among them. The University of Virginia, Virginia Tech, and Virginia State University are also founding members. CCAM's workforce development efforts support the Advanced Manufacturing sector.

CCAM will perform both directed research and generic research in its two core focus areas – manufacturing systems and surface engineering, where both research agendas are member-directed; organizing Industry and Tier 1 Members split their investments in CCAM between directed and generic projects. For directed projects, the sponsoring member company specifies and funds the research projects. Generic research investments, from all three tiers of membership, are aggregated to fund a generic research agenda jointly developed by scientific experts from each CCAM Member Company and academic institution. Information on CCAM's intellectual property (IP) policy for directed and generic research can be found in the IP Policy section.

Over the next five years, CCAM anticipates creating more than 60 new jobs as membership and funding increase. Aligning with the Commonwealth's push for job creation, CCAM expects to spur job growth in the state through its workforce development programs and by attracting new members that may be candidates for future manufacturing investments.

NASA Langley Research Center (NASA LaRC)

NASA LaRC was established in 1917 in Hampton, Virginia, and is the oldest NASA field center. With state-of-the-art wind tunnels – the Center boasts one of the largest of its kind in the world – simulation centers, laser labs, landing dynamics facilities, electromagnetic labs, and other unique assets, NASA LaRC conducts research and development of aerospace vehicles and systems for NASA, industry, and other government organizations. Approximately two thirds of research conducted at NASA LaRC is devoted to aeronautics, with the remaining third focused on space. There are four main areas of research at NASA LaRC that support NASA's primary mission: space exploration, space operations, atmospheric/earth sciences, and aeronautics. Recent initiatives have been in aerosciences and the characterization of atmospheres, systems analysis, structures and materials, and engineering and safety. These core competencies offer unique capabilities and support technology sectors such as Aerospace, Aviation, Life Sciences, Environment, and Advanced Manufacturing.

Aerosciences

The aerosciences capability at NASA LaRC provides simulation and testing in diverse atmospheres, such as those on and around Earth and Mars. The Center can create and evaluate advanced concepts with

systems analysis, systems engineering, simulation, technology development, technology demonstration, and infusion into air and space flight operations.

Systems Analysis

Systems analysis work at the Center has developed advanced concepts and architectures by using system and subsystem design techniques for break-through concepts, honest broker analysis for technology investment, and informed decision-making. Specific areas of expertise include mission architectures and systems concepts, systems concept development and technology assessment, and analysis and design method development.

Structures and Materials

NASA LaRC's structures and materials expertise targets advanced structural and material concepts, radiation protection, large space structures, durability and damage tolerance, nondestructive evaluation, and smart and self-healing materials and systems that are crucial to NASA's exploration goals. Researchers at NASA LaRC recognize the close relationship of aeronautics and space applications and adapt the techniques of one discipline for use in the other.

NASA LaRC focuses on the early stages of system definition, technology advancement, and private sector growth through the commercialization of its technology. NASA LaRC works collaboratively with other NASA Centers, industry, universities, and international partners to move concepts to usable, reliable components. In addition, its dedication to education and outreach, NASA LaRC makes available online resources and programs to students and teachers, thus helping shape the next generation of scientists and researchers.

National Institute of Aerospace (NIA)

NIA is a non-profit research and graduate education institute created to conduct leading-edge aerospace and atmospheric research, develop new technologies, and help inspire future scientists and engineers. Research at NIA supports an array of technology sectors, including Aerospace, Advanced Manufacturing, Environment, and Life Sciences. NIA's purpose is four-fold:

- To foster research collaboration among national laboratories, academia, and industrial partners that stimulates innovation and creativity
- To provide comprehensive graduate and continuing education in science and engineering via local campus presence and distance learning technologies
- To incubate and stimulate the commercialization of new intellectual property developed through NIA's research activities
- To promote aerospace science and engineering and provide outreach to the region and the nation

NIA conducts a broad range of scientific and engineering research sponsored by NASA, other government agencies, and the aerospace industry. In fact a number of NIA's scientists also work in various branches at NASA LaRC. NIA is working to develop several unique R&D brands in several areas including: boron nitride nano tube (BNNT) growth and applications and in uncertainly quantification (UQ), a design process for complex systems that determines likely outcomes when variables are uncertain.

NIA places a keen focus on outreach and education. Through an established education program, students work alongside researchers at NIA's partner organization, NASA LaRC; participate in innovative courses designed and led by field experts; and participate in leading-edge research programs. By providing training for teachers and creating engaging activities for middle and high school students, NIA strives to promote interest in science and technology.

Naval Surface Warfare Center Dahlgren Division (NSWCDD, Dahlgren)

The work performed at NSWCDD delivers affordable and capable 21st century warfighting and peace-keeping capabilities to the United States Navy, Joint Forces, and the nation. NSWCDD develops and supports systems, technologies, concepts, and tactics that enable military forces to conduct missions in surface warfare safely and effectively. As a valuable military research institute, NSWCDD understands the technical dimensions of military systems, recognizing needs, problems, and potential solutions.

Dahlgren conducts research in specific technology areas:

- Surface weapons technology, including directed energy
- Unmanned systems
- Sensors technologies, including radar, electric optical, infrared, and quantum sensors
- Management of electromagnetic environments
- Human systems integration
- Metamaterials/nanotechnology
- Network analysis and distributed systems
- Chemical and biological detection, decontamination, and collective protection
- Complex system architecture
- Software intensive systems
- Distributed systems

All of these sectors support the National Security technology sector, and also represent the Information Technology, Communications, and Advanced Manufacturing sectors.

Because of the nature of the laboratory, NSWCDD is not typically a research sponsor, but readily engages with other researchers in demonstrating new technology and transitioning it into the military and commercial sectors. This teaming approach to research allows NSWCDD to target different and more diverse research areas and leverage non-historical funding opportunities. For example, NSWCDD, in collaboration with local governments, state and federal agencies, and first responders, is developing a process that will fuse data from disparate sources, analyze it, and then re-present it in a broad-based usable format. Although not the sole recipient of budgeted funds, NSWCDD does use some discretionary dollars for work typically done at the front-end of the research, development, and production cycle – it develops system specifications, connects with industry, and provides in-service support.

NSWCDD's partnership programs encourage collaboration with the public sector, industry, and academia. Through Cooperative Research and Development Agreements (CRADAs), Navy-developed technology, expertise, and facilities are used to develop dual-use technologies applicable to the warfighter and the commercial marketplace. Educational partnership agreements allow NSWCDD to loan or donate excess equipment to schools and involve students and professors in research. Its staff can teach classes, provide career advice to students, and offer guidance in curriculum development. NSWCDD is actively involved with six Virginia universities and seven local public school systems. Agreements with local public school systems are promoting science, technology, engineering, and math (STEM) programs, which bring scientists and engineers into middle school classrooms for hands-on projects.

SRI Shenandoah Valley Center for Advanced Drug Research (SRI SV CADRE)

SRI Shenandoah Valley was established in December 2006 in Harrisonburg, Virginia; CADRE developed as part of the Biosciences Division of SRI International, which carries out basic research, drug discovery, and drug development and provides contract services. CADRE's mission is to find new ways to prevent, detect, and treat diseases of global importance by applying proteomics and protein engineering technologies. Research that supports this mission falls into three main areas: biotechnology, pharmaceuticals, and biosciences research. The Center currently employs about 40 staff members; with increased research opportunities and funding CADRE hopes to increase the number to 45 by the end of 2011. A leader in providing education and training to the academic community CADRE's workforce is a fusion of experienced research leaders, post-doctoral fellows in training, and undergraduate interns drawn from Virginia institutions.

Research at SRI SV CADRE is applied to three primary health issues:

- Global health and infectious diseases, including finding new diagnostics and therapies for tuberculosis and mosquito-borne illnesses (malaria and chikungunya) and addressing biothreat agents
- Metabolic diseases, focusing on diabetes, particularly diabetes related to insulin-resistance, as well as on drugs and biomarkers capable of more accurately predicting diabetes

- Biomarker discovery, leading to new diagnostics and therapies, as well as providing the foundation to personalized medicine

CADRE's research focus and strategic direction are regularly evaluated in light of industry advances and external funding trends. Every five years, a long-term vision is developed, identifying areas where CADRE can position itself as a leader in cutting-edge research.

Thomas Jefferson National Accelerator Facility (Jefferson Lab)

The Jefferson Lab is a 169-acre Department of Energy (DOE) facility located in Newport News, Virginia. It boasts state-of-the-art, one-of-a-kind facilities and technologies, setting it apart from other research labs around the globe. These resources and facilities encourage research in a variety of technology sectors, including Energy, Environment, Life Sciences, and Information Technology. In fact, the Jefferson Lab has an international user community of almost 1,400 researchers, taking advantage of its world-class R&D capabilities, staff experience, and facilities. As of the end of 1Q 2011, the Jefferson Lab had a staff of approximately 760, and each day, nearly 100 users from the United States and around the world visit and utilize the Lab and its resources. In addition to conducting research, the Jefferson Lab also provides outstanding science education programs for K-12 students, undergraduate and graduate students, and teachers.

Jefferson Lab's five priority areas leverage its strengths and provide a basis for teaming and partnering with other DOE laboratories, universities, and private sector partners. Research at the Jefferson Lab focuses on: experimental, theoretical, and computational nuclear physics; accelerator science; applied nuclear science and technology; and large-scale user facilities/advanced instrumentation. The Jefferson Lab also addresses issues in nuclear instrumentation, medical imaging, large-scale computing, materials science, and other related areas.

A specific project – and the primary mission of the Lab – is to utilize its unique Continuous Electron-Beam Accelerator Facility (CEBAF) to explore the fundamental nature of confined states of subatomic particles such as quarks and gluons. In accelerator science, the Jefferson Lab leads the world's development of the superconducting radio-frequency (SRF) technology utilized for CEBAF. In addition, Jefferson Lab is building a tunable free electron laser (FEL) capable of record-breaking power levels and has fostered the growth of key technologies for future state-of-the-art light sources.

The Jefferson Lab provides a unique facility for studying quark structures using continuous beams of high-energy polarized electrons. Its detector and data acquisition capabilities, coupled with high-energy electron beams, provide the highest luminosity capability in the world. With CEBAF, the Jefferson Lab has more integrated operating experience of superconducting linacs than any other institution. In addition, the Jefferson Lab has processed more multi-cell superconducting cavities to consistently higher performance levels than any other facility in the world.

Currently the Jefferson Lab is in the process of upgrading the CEBAF to 12 GeV to allow scientists to explore the complex make up of nucleons. Future initiatives include playing a leading role in the next large-scale light source and constructing an electron ion collider, which would ensure continued world leadership in nuclear physics.

Intellectual Property

Background

Intellectual property (IP) agreements are a critical element of successful research and commercialization. Straightforward "win-win" agreements are the foundation for successful research collaboration and commercialization of IP. However, it is unlikely that a "one-size-fits-all" IP agreement can be established for awards made under the Commonwealth Research Commercialization Fund (CRCF). The reasons for this stem from the diverse types of projects supported by CRCF as well as the diverse interests of the partners engaged in the contract. Moreover, it is important for all parties to evaluate the future benefits that will be assigned to them while constructing viable, long-term agreements.

IP agreements must consider multiple players and policies – federal policies, such as the Bayh-Dole Act; state policies; and university-specific or system-wide policies and interests, such as those of faculty and research staff, as well as those of Technology Transfer and Intellectual Property Offices. Additionally, the needs of private sector firms or other research collaborators must be considered. IP agreements must also take into account the nature of the research and the contributions of the collaborators, be they financial, intellectual, or otherwise. Academic IP agreements with corporate partners may reflect an institution's interest in developing a long-term relationship that encompasses scaled up research, educational opportunities, and factors beyond licensing or other revenues.

Examining IP agreements in order to streamline the process and establish consistency, particularly between Virginia's universities and the private sector, has been a topic of study and discussion for more than a decade. Despite many conversations and attempts to develop a standard IP policy for the Commonwealth, little progress has been made due to the complexity of the process and the difficulty inherent in a one-size-fits-all solution.

Approach

In developing an IP policy specifically for awards made under the CRCF program, CIT examined the Code of Virginia related to intellectual property, as well as IP agreements from in-state and out-of-state organizations. IP agreements were chosen both to understand the breadth of policies and to examine various models, particularly those designed for stimulating collaborative research and commercialization. The research community in Virginia recommended a number of out-of-state models to examine, including those associated with the University of California at Berkeley, the Rochester Institute of Technology, and the U.S. Department of Energy's "America's Next Top Energy Innovator" program.

Virginia

Virginia universities establish their own IP policies, which are usually negotiated on a case-by-case basis. University IP policies are approved by the State Council of Higher Education for Virginia (SCHEV), and each institution is required to submit an annual report regarding the assignment of its IP. In general, Virginia university technology transfer, patent, and/or IP offices in Virginia are funded through licensing fees rather than state or university general funds.

The Code of Virginia provides both autonomy and strict guidelines on IP matters. Among other IP-related topics, Section 23-4.3 of the Code instructs Boards of Visitors of state-supported institutions of higher education and the State Board for Community Colleges to adopt policies addressing the ownership, protection, assignment, and use of IP. Section 23-4.4 addresses assignment of IP; it authorizes Boards of Visitors, the State Board for Community Colleges, or their designees to assign any interest they possess in intellectual property, or in materials in which the institution claims an interest, provided that the assignment is in accord with the institutions' IP policy. However, assignment requires the Governor's prior written approval under certain conditions, including if the property was developed wholly or predominately through the use of state general funds, exclusive of capital assets, and if the IP was developed by an employee of the institution acting within the scope of his assigned responsibilities.

Pertinent to CRCF, Chapter 816 in the 2011 Virginia Acts of Assembly indicates that awards made from the CRCF shall not be considered state general funds for purposes of determining whether property was developed "wholly or predominantly" through the use of state general funds for purposes of Section 23-4.4 of the Code.

IP Models

IP agreements incentivize the advancement of knowledge, including commercialization, and consider the interests of the sponsor, researcher, and other relevant parties.

The Commonwealth Center for Advanced Manufacturing (CCAM), established a policy that addresses both its company-specific and generic research. Company-specific – or directed – research is solely funded by a corporate sponsor(s), and therefore the IP resides with that sponsor(s). Generic – or pre-competitive – research is jointly funded by investments made from all of CCAM's member companies; CCAM owns this IP and each member company receives a non-exclusive, global, non-royalty bearing license to the IP.

The University of California at Berkeley (UC Berkeley) promotes tech transfer of innovations developed at Berkeley, recognizing that commercialization is best performed by the private sector. Licensing is generally seen as a mechanism to steer technology into the community rather than as a revenue-

generating function. UC Berkeley manifests this philosophy through a variety of strategies, including exercising discretion in the application of IP policies of the UC system, petitioning for exceptions, establishing an industry contracting division within its IP office, and maintaining long-term corporate relationships.

The Rochester Institute of Technology established a new type of research partnership in 2007 that addresses research that is less likely to result in fundamental (and potentially valuable) new discoveries.[5] A contracting mechanism was designed to support smaller product development projects and solutions to specific company problems. Projects are typically funded at approximately $25,000 per semester. They have a duration of one to 12 months, with work generally suitable for master's and undergraduate students supervised by a faculty member. Additionally, IP development is possible; it may be used when IP is brought to the research collaboration/university by a partner. In this model, the company typically owns the IP, although Rochester Institute of Technology retains the right to publish and use the knowledge for education and internal research.

In order to spur commercialization of technologies developed by the National Laboratories, the U.S. Department of Energy (DOE) announced a new initiative in March 2011. Its "America's Next Top Energy Innovator" challenge includes provisions to reduce the cost and administrative requirements for start-up companies to obtain an option agreement to license some of the patents held by the National Laboratories. The upfront cost of licensing patents in a specific technology was reduced to $1,000 for portfolios of up to three patents, representing a savings of $10,000-$50,000 in upfront fees. DOE also established a standard set of terms for start-up companies. These, however, may not be attractive to many companies. Companies exercising the option to negotiate an exclusive license must provide, for instance, a commercialization plan that is acceptable to the National Lab they are working with. Additionally, companies that do not exercise the option must provide that Lab a summary of the results of the evaluation of the technology and the firm's reason for not exercising its option. In this case, the government retains march-in rights, and the firm is required to manufacture the licensed products in the United States if it is targeting a U.S. market.

Conclusion

Intellectual property agreements are a cornerstone of success in the research enterprise. Straightforward, win-win agreements that provide incentives for all parties can drive collaboration, commercialization, and other desirable outcomes. IP agreements, however, are influenced by an array of policies and perspectives. This includes the nature of the research and the longstanding, individual policies among Virginia universities, research institutions, and industry.

[5]Goldie Blumenstyk, "RIT Trades Invention Rights for Research Dollars and Says You Should, Too," *The Chronicle of Education,* http://chronicle.com/article/RIT-Trades-Invention-Reights/48507/ (21 September 2009).

For awards made under CRCF, the FY2012 policy requires that an intellectual property agreement be executed, when IP is or may be jointly developed, before funding is disbursed, and that execution of the agreement may occur no later than 60 days from the date the award is announced by CIT. Therefore, universities or other parties that apply for CRCF funding will be expected to use their respective existing approved IP policies and, as appropriate, to negotiate an agreement that has been accepted by and indicates the rights and obligation of all parties.

Summary

This phase of the R&T Roadmap examined research strengths, priorities, and opportunities in the Commonwealth's private sector, universities, research institutes, and federal labs to identify and align key industry sectors within the state and, ultimately, assess which sectors present the Commonwealth with the most commercial promise. This iterative assessment looked at regional priorities, existing and projected research and commercialization capabilities, economic development initiatives, and an evaluation of the external – national and global – climate. The findings represent an initial, high-level direction the Commonwealth may take for future investments including research and technologies eligible for CRCF funding in the October 2011 solicitation. These opportunities follow:

- **Advanced Manufacturing**, with particular interest in semiconductors, unmanned vehicles, robotics, remote monitoring and sensing, surface engineering, chemicals, advanced materials, and nanotechnology – especially nanoelectronics and nanomedicine
- **Aerospace**, with particular interest in launch vehicles and commercial space flight
- **Communications,** with particular interest in broadband and wireless telecommunications
- **Cyber security**, including data center security, network and perimeter security, authorization and authentication technologies, disaster recovery and continuity of operations technologies, and application and device security
- **Energy**, with particular interest in smart grid, green construction including retrofitting, nuclear plant safety and support, wind technologies, biofuels, and waste-to-energy applications
- **Environment,** with particular interest in marine science and water and air quality monitoring and control
- **Information Technology**, with particular interest in software and application development, and data management, analytics, and storage
- **Life Sciences**, with particular interest in biotechnology, biomedicine, health IT, bioinformatics, biomarkers, biometrics, personalized medicine, remote care delivery, drug discovery, and computer-assisted drug design
- **Modeling and Simulation**, with particular interest in energy, transportation, healthcare, and homeland security and defense applications
- **Nuclear Physics**, with particular interest in advanced manufacturing, energy, environment, life sciences, information technology applications, and a 4th generation light source
- **Transportation**, with particular interest in vehicle telematics, vehicle and driver performance monitoring, and intelligent transportation systems

Subsequent phases of the Roadmap will refine areas where efforts should be focused, including identifying basic and applied research opportunities; developing a process for cataloging research endeavors; reviewing and potentially revising an IP policy for CRCF awards; and addressing capital construction needs. In addition, the next phase will place Virginia's strengths within a national and

regional context to help advise the Commonwealth on research and commercialization opportunities and strategies.

APPENDIX A: Legislation

§ 2.2-2221.2. Commonwealth Research and Technology Strategic Roadmap

A. *The Authority shall develop the Commonwealth Research and Technology Strategic Roadmap (the Roadmap), a comprehensive research and technology strategic roadmap for the Commonwealth to identify research areas worthy of economic development and institutional focus. The goal of the Roadmap shall be to develop a cohesive and comprehensive framework through which to encourage collaboration between the Commonwealth's institutions of higher education, private sector industries, and economic development entities in order to focus on the complete life cycle of research, development, and commercialization. The framework shall serve as a means to (i) identify the Commonwealth's key industry sectors in which investments in technology should be made by the Commonwealth, which may include but are not limited to the fields of energy, conservation, environment, microelectronics, robotics and unmanned vehicle systems, advanced shipbuilding, or lifespan biology and medicine, (ii) identify basic and applied research opportunities in these sectors that exhibit commercial promise, (iii) encourage commercialization and economic development activities in the Commonwealth in these sectors, an (iv) help ensure that investments in basic and applied research are made prudently in focused areas for projects with significant potential for commercialization and economic growth in the Commonwealth. In developing the Roadmap, the Authority shall:*

1. *Review the strategic plan for each research university in the Commonwealth to identify common themes;*
2. *Catalog the Commonwealth's assets in order to identify the areas of research and development in which the Commonwealth has a great likelihood of excelling in applied research and commercialization;*
3. *Make recommendations for the alignment of research and development and economic growth in the Commonwealth, indentifying the industry sectors in which the Commonwealth should focus its research, development, investment, and economic development efforts;*
4. *Establish a process for maintaining the inventory of the Commonwealth's current research and development endeavors in both the public and private sector that can be used to attract research and commercialization excellence in the Commonwealth;*
5. *Make recommendations to the Six-Year Capital Outlay Plan Advisory Committee established pursuant to § 2.2-1516 regarding capital construction needs at state institutions of higher education necessary to excel in basic and applied research in identified industry sectors; and*
6. *Develop a policy regarding the ownership and licensing of intellectual property developed through the use of awards from the Commonwealth Research Commercialization Fund.*

B. *In developing the Roadmap, the Authority shall solicit feedback from the Research and Technology Investment Advisory Committee; public and private institutions of higher education in the Commonwealth; federal research and development assets in the Commonwealth including but not limited to NASA Langley Research Center, the Naval Surface Warfare Center, Dahlgren Division, and the*

Thomas Jefferson National Accelerator Facility (Jefferson Lab); regional technology councils in the Commonwealth; and the private sector.

C. *The Authority shall review and update the Roadmap at least once every three years.*

D. *The Authority shall submit the Roadmap, and any subsequent updates, to the Governor and the chairmen of the Senate Finance Committee, the House Appropriations Committee, the Senate Committee on General Laws and Technology, the House Committee on Science and Technology, and the Joint Commission of Technology and Science.*

APPENDIX B: Standard Terminology

Terminology often differs among academia, research institutes and federal labs, and industry. Even within industry, there are often nuances in expression. The table below represents the terminology used and the 4- and 6-digit NAICS codes that correlate, as developed by Chmura Economics & Analytics.

4 Digit-NAICS	NAICS Description	Innovation Sector	6 Digit-NAICS
1125	Aquaculture	Life Sciences	112519
2121	Coal Mining	Energy	212111
2122	Metal Ore Mining	Energy	212291
2131	Support Activities for Mining	Energy	213113
2211	Electric Power Generation, Transmission and Distribution	Energy	221112
2212	Natural Gas Distribution	Energy	221210
2371	Utility System Construction	Energy	237130
2373	Highway, Street, and Bridge Construction	Transportation	237310
2382	Building Equipment Contractors	Environment	238210
3241	Petroleum and Coal Products Manufacturing	Energy	
3251	Basic Chemical Manufacturing	Energy	325188
3254	Pharmaceutical and Medicine Manufacturing	Life Sciences	325412
3323	Architectural and Structural Metals Manufacturing	Energy	332313
3324	Boiler, Tank, and Shipping Container Manufacturing	Energy	332410, 332420
3329	Other Fabricated Metal Product Manufacturing	Energy	332911
3332	Industrial Machinery Manufacturing	Advanced Manufacturing	333295
3334	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing	Energy	333414
3336	Engine, Turbine, and Power Transmission Equipment Manufacturing	Advanced Manufacturing	333618
3339	Other General Purpose Machinery Manufacturing	Advanced Manufacturing	333911, 333994
3341	Computer and Peripheral Equipment Manufacturing	Advanced Manufacturing	
3342	Communications Equipment Manufacturing	Advanced Manufacturing	334220, 334290

3344	Semiconductor and Other Electronic Component Manufacturing	Advanced Manufacturing	334413, 334416
3345	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing	Transportation	334511, 334512, 334513, 334514, 334515, 334516, 334517, 334519
3353	Electrical Equipment Manufacturing	Advanced Manufacturing	335311, 335312
3359	Other Electrical Equipment and Component Manufacturing	Advanced Manufacturing	335911, 335931, 335999
3361	Motor Vehicle Manufacturing	Transportation	336120
3362	Motor Vehicle Body and Trailer Manufacturing	Transportation	336211
3363	Motor Vehicle Parts Manufacturing	Transportation	336322, 336360
3364	Aerospace Product and Parts Manufacturing	Aerospace	
3366	Ship and Boat Building	Transportation	336611, 336612
3369	Other Transportation Equipment Manufacturing	Transportation	336992, 336999
3391	Medical Equipment and Supplies Manufacturing	Life Sciences	
4234	Professional and Commercial Equipment and Supplies Merchant Wholesalers	Advanced Manufacturing	423490
4235	Metal and Mineral (except Petroleum) Merchant Wholesalers	Energy	
4238	Machinery, Equipment, and Supplies Merchant Wholesalers	Transportation	423860
4811	Scheduled Air Transportation	Aviation	
4812	Nonscheduled Air Transportation	Aviation	
4821	Rail Transportation	Transportation	
4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Transportation	
4841	General Freight Trucking	Transportation	484110, 484121
4842	Specialized Freight Trucking	Transportation	
4881	Support Activities for Air Transportation	Aviation	
4883	Support Activities for Water Transportation	Transportation	
5112	Software Publishers	Information Technology	
5191	Other Information Services	Information Technology	
5171	Wired Telecommunications Carriers	Communication	

5172	Wireless Telecommunications Carriers (except Satellite)	Communication	
5174	Satellite Telecommunications	Communication	
5179	Other Telecommunications	Communication	
5182	Data Processing, Hosting, and Related Services	Information Technology	518210
5413	Architectural, Engineering, and Related Services	Environment	541330, 541360, 541380
5415	Computer Systems Design and Related Services	Information Technology	541512, 541513
5416	Management, Scientific, and Technical Consulting Services	Environment	541620, 541690
5417	Scientific Research and Development Services	Environment	541711, 541712
5511	Management of Companies and Enterprises	Information Technology	
5612	Facilities Support Services	Environment	
5622	Waste Treatment and Disposal	Environment	562211, 562213, 562219
5629	Remediation and Other Waste Management Services	Environment	
6215	Medical and Diagnostic Laboratories	Life Sciences	621511, 621512
9231	Administration of Human Resource Programs	Life Sciences	923120
9241	Administration of Environmental Quality Programs	Environment	924110
9261	Administration of Economic Program	Energy	926130
9271	Space Research and Technology	Aerospace	
9281	National Security and International Affairs	National Security	

APPENDIX C: Regional Industry Priorities

Region	Industry	Niche Opportunity
Northern Virginia	Advanced Manufacturing	Semiconductors
		Nanotechnology
	Aerospace	Satellites
		Launch Vehicles
		Missile Defense Systems
	Cyber Security	Cyber Security
		Information Assurance
		Homeland Security and Defense
	Energy	Green Engineering and Construction
		Smart Grid Applications and Analytics
		Alternative Energy
	Information Technology	Data Management, Analytics, and Storage
		Software and Application Development
		Telecommunications and Broadband
		Modeling and Simulation
	Life Sciences	Biotechnology and Biometrics
		Bioinformatics
		Health IT
		Personalized Medicine
		Medical Devices and Software
Hampton Roads	Advanced Manufacturing	Next Generation Shipbuilding
		Robotics and Unmanned Vehicles
		Port Security
		Sensors and Environmental Monitoring
	Aerospace	Remote Environmental Monitoring
		Support to Federal Research
		Instrumentation and Calibration Services
		Autonomous Systems for Space Exploration
	Energy	Offshore Wind Component Manufacturing, Installation, and Service
		Power Electronics Component Manufacturing, System Integration, and Service
		Algal Biofuel Production
		Landfill and Biomass Waste-to-Energy Power Generation
	Life Sciences	Computer-Assisted Drug Design
		Regenerative Medicine
		Cancer Treatment and Prevention
	Modeling & Simulation	Transportation, Logistics, and Evacuations
		Homeland Security and Defense: Extreme Event and

		Risk Analysis, Emergency Management
		Health Care: Treatment and Rehabilitation, Health Care and Disease Management
		Cognitive Development and Rehabilitation, Training Applications
		Business and Supply Chain Optimization and Planning
		Hardware and Software Development for Simulators and Training Devices
Richmond	Advanced Manufacturing	Surface Engineering
		Robotics and Automated Materials Handling
		Chemicals
	Energy	Energy Storage and Efficiency
		Smart Grid Applications and Analytics
		Smart Appliances
		Alternative Energy
	Information Technology	Cyber Security
		Data Management, Analytics, and Storage
		Software and Application Development
	Life Sciences	Biotechnology
		Pharmaceuticals
		Health IT
		Medical Devices and Software
Roanoke – Blacksburg	Energy	Power Electronics
		Smart Grid Technology and Applications
		Energy Data Mining, Management, and Analytics
		Smart and Net-Zero Construction
		Heavy Duty Vehicle Conversion to Hybrid
		Carbon Capture and Storage
	Information Technology	Data Management, Analytics, and Storage
		Web 2.0 and Social Networks
		Software and Application Development
		Utility Computing, Web Services
	Life Sciences	Bioinformatics
		Drug Discovery and Design
		Personalized Medicine
		Remote Patient Monitoring and Care Delivery
		Integration of Social Media and Technology
		Health-related Wireless Sensors and Networks
	Transportation	Intermodal Port Operation
		Vehicle/Driver Monitoring
		Smart Infrastructure Sensing and Technology
		Autonomous Vehicles
		Vehicle Telematics
Region 2000	Advanced Manufacturing	Integrated Communications
		Sensing and Measurement Technologies

		Machine Support to Nuclear Industry
		Robotics
		Nuclear Materials Container Design, Analysis, Fabrication, and Testing
		Welding Technologies
	Communications	Wireless RF
		Remote Sensor Development and Monitoring
		Software-Defined (Cognitive) Radio
		Integration of 4th Generation Cell Technology into Radio Use
	Energy	Existing Nuclear Plant Life Extension
		Nuclear Fuel Reprocessing
		Medical Isotope Reactors
		Nuclear Control Room Simulation
		Plant and Grid Security
		Smart Grid
Shenandoah Valley	Energy	Alternative Transportation Fuels
		Energy Data Analytics
		Energy Usage Monitoring Devices
		Energy Storage Devices
		Wind Turbine Blade Testing
		Production of Renewable Energy From Customer-Owned Wind and Solar Systems
		Biomass-to-Energy Conversion
	Information Technology	Information Assurance
		Data Management and Storage
		Education Software Development
		Information Assurance
	Life Sciences and Agriculture	Biotechnology
		Drug Research
		Cancer Treatment
		Biothreats and Defense
Southern Piedmont	Advanced Manufacturing	Advanced Fuel Cell Research and Manufacturing
		Custom Manufacturing
		Robotics and Unmanned Systems
		Nano Solar Cells Used to Make Hydrogen for Fuel Cells
	Energy	Plug-In Hybrid Electric Conversion
		Energy Storage Platforms, Including NaBH4/H2O2 Fuel Cells in Autonomous Vehicles and Robots, and Ultra-Capacitor Technology
		Vehicle Performance
		Energy-Related Mining and Equipment Technology
	Information Technology	Health IT
		Data Analytics
		Data Imaging and Forms Processing

		Information Security
Southwest Virginia	Energy and Natural Resources Industry	Bioenergy - Cellulosic Ethanol
		Landfill Gas Utilization
		Coal Bed Methane Conversion
		Biomass Waste-to-Energy
		Plugless Power
	Information Technology	Data Analytics and Storage
		Application Development
	Life Sciences and Healthcare	Health Information
		Remote Patient Monitoring and Care Delivery
		Personalized Medicine
		Tobacco Use for Incubating Vaccines
		EMR Data Storage, Mining, and Analytics
Fredericksburg	Energy	Green Technology – Efficiency and Conservation
		Green Construction and Net Zero Buildings
		Smart Grid
		Smart Meter Technology
	Information Technology	Cyber Security
		Information Assurance
		Software Development for Data Analytics
	National Security	Secure Federal Telework
		Human Factors Engineering
		Defense Logistics Training
		Live Fire Capabilities
Charlottesville	Life Science	Biotechnology
		Health IT
		Medical Devices and Software
	National Security	Defense Intelligence
		Cyber Security
		Information Assurance

APPENDIX D: Virginia Universities' R&T Priorities

Institution	Industry	Niche Opportunity
College of William & Mary (CWM)	Advanced Manufacturing	Semiconductor Technologies
	Advanced manufacturing	Robotics
	Advanced Manufacturing	Electronic Components
	Communications	Wireless Networks
	Communications, National Security	Secure Communications/Cyber Security
	Energy	Wind Energy
	Energy	Biofuels
	Energy	Waste Recovery
	Energy	Ocean Wave Engineering
	Energy	Grid Security
	Energy	Energy Storage Platforms
	Energy, Environment	Carbon Sequestration Technologies
	Environment	Water Quality
	Environment	Environmental/Climate Change Research
	Environment	Environmental Policy
	Environment	Land Use Law
	Environment, Nanotechnology	Environmental Impacts of Nanotechnologies
	Information Technology	Data Analytics
	Information Technology	High-Performance Computing
	Information Technology	Education Technologies
	Information Technology, Life Sciences	Bioinformatics
	Information Technology, National Security	Network Security/Cyber Security
	Life Sciences	Medical Device Development
	Life Sciences	Diagnostics and Assays
	Life Sciences	Imaging and Radiology
	Life Sciences	Inflammation Research
	Life Sciences	Neuroscience
	Life Sciences	Public Health and Aging
	Life Sciences	Biomarkers
	Life Sciences	Advanced Non-Invasive Live

		Animal Imaging
	Life Sciences	Aquaculture
	Materials	Construction Materials
	Materials	Polymers
	Modeling and Simulation	Modeling and Simulation
	Nanotechnology	Nanomaterials
	Nanotechnology	Nanoscale Devices
	Nanotechnology	Nanoscale Electronics
	Nanotechnology	Nanomanufacturing/Nanotube Applications
	National Security	National Security Technologies
	Sensors	Environmental Sensing
	Sensors	Remote Sensing
	Sensors	Sensor Networks
	Transportation	Road Construction and Materials
	Transportation	Materials/Pavement Research
		Optics and Lasers
Eastern Virginia Medical School (EVMS)	Information Technology	Modeling and Simulation
	Information Technology, Life Sciences	Integration of Social Media and Patient Care
	Life Sciences	Sensor Networks
	Life Sciences	Sleep Disorder Technologies
	Life Sciences	Personalized Medicine
	Life Sciences	Medical Device Development
	Life Sciences	Diagnostics and Assays
	Life Sciences	Imaging and Radiology
	Life Sciences	Research Reagents
	Life Sciences	Neuroscience
	Life Sciences	Public Health and Aging
	Life Sciences	Therapeutics
	Life Sciences	Biomarkers
	Life Sciences	Assisted Reproductive Technologies/IVF
	Life Sciences	Biorepository
	Life Sciences	Education Technologies
George Mason University (GMU)	Advanced Manufacturing	Robotics
	Advanced Manufacturing	Robotics
	Aerospace	Airspace Safety Analysis
	Aerospace	Strategic Planning and Analysis of Air Transportation Industry

	Aerospace, Information Technology	Airport and Airspace Simulation, Analysis, and Optimization
	Communications	Secure Communications/Cyber Security
	Communications	Wireless Networks
	Communications	Mobile Communications
	Energy	Plug-in Electric Vehicles
	Energy	Smart Grid Technologies
	Energy	Nuclear Power Education
	Environment	Water Quality
	Environment	Environment/Climate Change Research
	Environment	Environmental Policy
	Environment	Water Resources
	Information Technology	Computer Software
	Information Technology	Data Analytics
	Information Technology	Network Security/Cyber Security
	Information Technology	High Performance Computing
	Information Technology	Modeling and Simulation
	Information Technology	Information Security and Assurance
	Information Technology	Computer Graphics
	Information Technology	Computer Vision
	Information Technology	Databases and Information Retrieval
	Information Technology	Evolutionary Computing
	Information Technology	Machine Learning
	Information Technology	Education Technologies
	Information Technology, Life Sciences	Bioinformatics
	Life Sciences	Personalized Medicine
	Life Sciences	Neuroscience
	Life Sciences	Public Health and Aging
	Life Sciences	Therapeutics
	Life Sciences	Immunology and Infectious Diseases
	Life Sciences	Nutrition
	Materials	Polymers
	Nanotechnology	Nanomaterials
	Nanotechnology	Nanoscale Bio-based Power

		Sources
	Nanotechnology	Nanotechnology
	Transportation	Driver Monitoring
	Transportation	Highway Transportation Engineering
	Transportation	Intelligent Transportation Systems
	Transportation	Sea Shipping Infrastructure Analysis
	Transportation	Transportation Policy
	Transportation	Freight
	Transportation	Marine Highway
	Sensors	Command and Control
	Sensors	Secure Sensor Networks
	Sensors	Remote Sensing
	Sensors	Sensor Networks
George Washington University (GWU)	Advanced Manufacturing	Semiconductor Technologies
	Advanced Manufacturing	Robotics
	Advanced Manufacturing	Electronic Components
	Aerospace, Transportation	Aerospace Technologies
	Communications	Mobile Communications
	Energy	Smart Grid Technologies
	Energy	Grid Security
	Energy	Energy Storage Platforms
	Environment	Waste Recovery
	Environment	Water Quality
	Environment	Green/Sustainable Building Design (Residential and Commercial)
	Environment	Sustainable Landscape Design
	Environment	Environmental/Climate Change Research
	Environment	Environmental Policy
	Environment	Green Procurement
	Environment	Environmental Impacts of Nanotechnologies
	Information Technology	Computer Software
	Information Technology	Cloud Computing
	Information Technology	Data Analytics
	Information Technology	Network Security/Cyber Security

	Information Technology	High Performance Computing
	Information Technology	Modeling and Simulation
	Information Technology	Education Technologies
	Information Technology, Life Sciences	Bioinformatics
	Life Sciences	Personalized Medicine
	Life Sciences	Remote Patient Monitoring and Care Delivery
	Life Sciences	Integration of Social Media and Patient Care
	Life Sciences	Diagnostics and Assays
	Life Sciences	Imaging and Radiology
	Life Sciences	Neuroscience
	Life Sciences	Public Health and Aging
	Life Sciences	Pharmaceuticals
	Life Sciences	Therapeutics
	Life Sciences	Biomarkers
	Life Sciences	Drug Delivery
	Life Sciences	Computational Systems Biology
	Life Sciences	Epidemiology
	Life Sciences	Pathogenesis of HIV/AIDS
	Nanotechnology	Nanomaterials
	Nanotechnology	Nanoscale Devices
	Nanotechnology	Nanoscale Electronics
	Nanotechnology	Nanomanufacturing/Nanotube Applications
	Materials	Polymers
	Materials, Transportation	Bridge Construction and Materials
	Transportation	Vehicle Safety Technologies/Research
	Transportation	Traffic Advisory and Signaling Systems
	Transportation	Driver Monitoring
	Transportation	Vehicle Performance
		Optics and Lasers
James Madison University (JMU)	Advanced Manufacturing	Robotics
	Communications	Wireless Networks
	Energy	Plug-in Electric Vehicles
	Energy	Wind Energy

	Energy	Smart Grid Technologies
	Energy	Grid Security
	Energy	Biofuels
	Environment	Waste Recovery
	Environment	Water Quality
	Environment	Green/Sustainable Building Design (Residential and Commercial)
	Environment	Environment/Climate Change Research
	Environment	Environmental Policy
	Information Technology	Computer Software
	Information Technology	Network Security/Cyber Security
	Information Technology	Modeling and Simulation
	Information Technology	Computer Software
	Information Technology	Education Technologies
	Information Technology	National Security Technologies
	Life Sciences	Public Health and Aging
	Materials	Polymers
	Nanotechnology	Nanomaterials
	Sensors	Remote Sensing
Old Dominion University (ODU)	Advanced Manufacturing	Semiconductor Technologies
	Advanced Manufacturing	Robotics
	Aerospace	Aerospace Technologies
	Communications	Cognitive Radio
	Communications	Wireless Networks
	Communications	Mobile Communications
	Energy	Biofuels
	Energy	Photovoltaic Technologies
	Energy	Wind Energy
	Energy	Ocean Wave Engineering
	Energy	Smart Grid Technologies
	Energy	Power Electronics/Power Conversion
	Energy, Environment	Carbon Sequestration Technologies
	Environment	Water Quality
	Information Technology	Computer Software
	Information Technology	Cloud Computing

	Information Technology	Network Security/Cyber Security
	Information Technology	High Performance Computing
	Information Technology	Modeling and Simulation
	Information Technology	Integration of Social Media and Patient Care
	Information Technology, Life Sciences	Bioinformatics
	Life Sciences	Targeted Delivery of Nanomedicine
	Life Sciences	Remote Patient Monitoring and Care Delivery
	Life Sciences	Medical Device Development
	Life Sciences	Diagnostics and Assays
	Life Sciences	Imaging and Radiology
	Life Sciences	Biomarkers
	Nanotechnology	Nanomaterials
	Nanotechnology	Nanoscale Electronics
	Nanotechnology	Nanomanufacturing/Nanotube Applications
	Sensors	Environmental Sensing
	Sensors	Remote Sensing
	Sensors	Sensor Networks
	Transportation	Autonomous Vehicle Technology
	Transportation	Vehicle Safety Technologies/Research
	Transportation	Traffic Advisory and Signaling Systems
	Transportation	Driver Monitoring
	Transportation	Shipbuilding Technologies
University of Virginia (U.Va.)	Advanced Manufacturing	Semiconductor Technologies
	Advanced Manufacturing	RF/VLSI Circuit Design
	Advanced Manufacturing	Robotics
	Advanced Manufacturing	Electronic Components
	Aerospace	Aerospace Components Engineering
	Communications	Mobile Communications Equipment
	Communications	Secure Communications/Cyber Security
	Communications	Wireless Networks

	Communications	Mobile Communications
	Energy	Biofuels
	Energy	Photovoltaic Technologies
	Energy	Wind Energy
	Energy	Smart Grid Technologies
	Energy	Grid Security
	Energy	Energy Storage Platforms
	Energy	Energy Metering Equipment
	Energy	Energy Systems Engineering
	Energy, Environment	Carbon Sequestration Technologies
	Environment	Water Quality
	Environment	Green/Sustainable Building Design (Residential and Commercial)
	Environment	Sustainable Landscape Design
	Environment	Environment/Climate Change Research
	Environment	Environmental Policy
	Environment, Nanotechnology	Environmental Impacts of Nanotechnologies
	Information Technology	Computer Software
	Information Technology	Cloud Computing
	Information Technology	Data Analytics
	Information Technology	Network Security/Cyber Security
	Information Technology	High Performance Computing
	Information Technology	Modeling and Simulation
	Information Technology	Visualization
	Information Technology	Education Technologies
	Information Technology	National Security Technologies
	Information Technology, Life Sciences	Bioinformatics
	Information Technology, Life Sciences	Remote Patient Monitoring and Care Delivery
	Information Technology, Life Sciences	Integration of Social Media and Patient Care
	Life Sciences	Medical Device Development
	Life Sciences	Diagnostics and Assays
	Life Sciences	Imaging and Radiology
	Life Sciences	Research Reagents

	Life Sciences	Inflammation Research
	Life Sciences	Neuroscience
	Life Sciences	Public Health and Aging
	Life Sciences	Pharmaceuticals
	Life Sciences	Therapeutics
	Life Sciences	Biomarkers
	Life Sciences	Drug Delivery
	Life Sciences	Cancer Research
	Life Sciences	Personalized Medicine
	Materials	Polymers
	Materials	Materials Engineering
	Materials	Construction Materials
	Nanotechnology	Nanomaterials
	Nanotechnology	Nanoscale Devices
	Nanotechnology	Nanoscale Electronics
	Nanotechnology	Nanomanufacturing/Nanotube Applications
	Nanotechnology	Targeted Delivery of Nanomedicine
	Sensors	Environmental Sensing
	Sensors	Remote Sensing
	Sensors	Sensor Networks
	Transportation	Autonomous Vehicle Technology
	Transportation	Vehicle Safety Technologies/Research
	Transportation	Driver Monitoring
	Transportation	Shipbuilding Technologies
	Transportation	Transportation Engineering
	Transportation	Vehicle Performance
		Optics and Lasers
Virginia Commonwealth University (VCU)	Advanced Manufacturing	Semiconductor Technologies
	Advanced Manufacturing	RF/VLSI Circuit Design
	Advanced Manufacturing	Robotics
	Aerospace	Aerospace Technologies
	Communications	Cognitive Radio
	Communications	Wireless Networks
	Communications	Mobile Communications
	Communications	SVMs in Coder and Encoder Design
	Communications, National	Secure Communications/Cyber

	Security	Security
	Energy	Biofuels
	Energy	Photovoltaic Technologies
	Energy	Smart Grid Technologies
	Energy	Nuclear Engineering
	Energy	Mining in Power Engineering Data
	Energy	Nuclear Fuel Processing
	Energy, Materials	Nuclear Materials
	Energy, Sensors	Radiation Detection
	Environment	Water Quality
	Environment	Environmental Policy
	Environment	Environmental/Climate Change Research
	Environment	Green/Sustainable Building Design (Residential and Commercial)
	Information Technology	Computer Software
	Information Technology	Cloud Computing
	Information Technology	Data Analytics
	Information Technology	High-Performance Computing
	Information Technology	Time-Predictable Computing for Safety-Critical Systems
	Information Technology	Low-Power Computing in Handheld Devices
	Information Technology	Mining in Chemical Engineering Data
	Information Technology	Education Technologies
	Information Technology	Interactive and Mobile Education Systems
	Information Technology, Life Sciences	Imaging and Radiology
	Information Technology, Life Sciences	Remote Patient Monitoring and Care Delivery
	Information Technology, National Security	Network Security/Cyber Security
	Information Technology, National Security	Machine Learning and Data Mining (Face Recognition) in Security Databases
	Life Sciences	Bioinformatics

	Life Sciences	Personalized Medicine
	Life Sciences	Medical Device Development
	Life Sciences	Diagnostics and Assays
	Life Sciences	Inflammation Research
	Life Sciences	Neuroscience
	Life Sciences	Pharmaceuticals
	Life Sciences	Therapeutics
	Life Sciences	Biomarkers
	Life Sciences	Drug Delivery
	Life Sciences	Oyster Aquaculture
	Life Sciences, Nanotechnology	Targeted Delivery of Nanomedicine
	Life Sciences, Sensors	Physiological Sensors
	Materials	Polymers
	Materials	Smart Materials
	Modeling and Simulation	Modeling and Simulation
	Nanotechnology	Nanomaterials
	Nanotechnology	Nanoscale Devices
	Nanotechnology	Nanoscale Electronics
	Sensors	Environmental Sensing
	Sensors	Remote Sensing
	Sensors	Sensor Networks
	Sensors	Abnormal Detection
	Sensors	Strain Sensing
	Sensors	Chemical Sensing
	Transportation	Machine Learning Approaches to Traffic Prediction
	Transportation	Autonomous Vehicle Technology
		Optics and Lasers
Virginia Tech	Advanced Manufacturing	Semiconductor Technologies
	Advanced Manufacturing	RF/VLSI Circuit Design
	Advanced Manufacturing	Robotics
	Advanced Manufacturing	Electronic Components
	Aerospace	Aerospace Technologies
	Communications	Cognitive Radio
	Communications	Secure Communications/Cyber Security
	Communications	Wireless Networks
	Communications	Mobile Communications
	Communications	Antenna Design

	Communications	Mobile Communications Equipment
	Energy	Biofuels
	Energy	Energy Systems Engineering
	Energy	Natural Gas Distribution
	Energy	Coal Research
	Energy	Mining Engineering
	Energy	Plug-in Hybrid System
	Energy	Energy Metering Equipment
	Energy	Photovoltaic Technologies
	Energy	Wind Energy
	Energy	Geothermal Energy
	Energy	Ocean Wave Engineering
	Energy	Smart Grid Technologies
	Energy	Grid Security
	Energy	Power Electronics/Power Conversion
	Energy	Energy Storage Platforms
	Energy	Sunlight-to-Hydrogen Generation
	Energy	Energy Harvesting
	Energy	Smart Lighting
	Energy	Fuel additives
	Energy	Environmental/Climate Change Research
	Energy, Environment	Carbon Sequestration Technologies
	Energy, Transportation	Plug-in Electric Vehicles
	Environment	Green/Sustainable Building Design (Residential and Commercial)
	Environment	Sustainable Landscape Design
	Environment	Water Quality
	Environment	Environmental Policy
	Environment	Waste Recovery
	Environment	Environmental Impacts of Nanotechnologies
	Information Technology	Computer Software
	Information Technology	Cloud Computing
	Information Technology	Data Analytics

	Information Technology	Network Security/Cyber Security
	Information Technology	High Performance Computing
	Information Technology	Modeling and Simulation
	Information Technology	Visualization
	Information Technology	Education Technologies
	Information Technology	National Security Technologies
	Information Technology/Life Sciences	Bioinformatics
	Life Sciences	Personalized Medicine
	Life Sciences	Remote Patient Monitoring and Care Delivery
	Life Sciences	Integration of Social Media and Patient Care
	Life Sciences	Medical Device Development
	Life Sciences	Diagnostics and Assays
	Life Sciences	Imaging and Radiology
	Life Sciences	Research Reagents
	Life Sciences	Inflammation Research
	Life Sciences	Neuroscience
	Life Sciences	Public Health and Aging
	Life Sciences	Pharmaceuticals
	Life Sciences	Therapeutics
	Life Sciences	Biomarkers
	Life Sciences	Drug Delivery
	Life Sciences	Immunology/Infectious Diseases
	Life Sciences	Regenerative Medicine/Oncology
	Life Sciences	Nutrition and Obesity
	Life Sciences	Aquaculture
	Life Sciences	Veterinary Vaccines
	Life Sciences	Plant Germplasm
	Life Sciences, Nanotechnology	Targeted Delivery of Nanomedicine
	Materials	Materials/Pavement Research
	Materials	Construction Materials
	Materials	Polymers
	Materials, Transportation	Road Construction and Materials
	Materials, Transportation	Bridge Construction and Materials
	Nanotechnology	Nanomaterials

	Nanotechnology	Nanoscale Devices
	Nanotechnology	Nanoscale Electronics
	Nanotechnology	Nanomanufacturing/Nanotube Applications
	Sensors	Environmental Sensing
	Sensors	Remote Sensing
	Sensors	Sensor Networks
	Transportation	Autonomous Vehicle Technology
	Transportation	Vehicle Safety Technologies/Research
	Transportation	Traffic Advisory and Signaling Systems
	Transportation	Driver Monitoring
	Transportation	Shipbuilding Technologies
	Transportation	Transport Network Simulations
	Transportation	Vehicle Performance
	Transportation	Crash Biomechanics
		Optics and Lasers

APPENDIX E: Research Institute and Federal Laboratory R&T Priorities

Organization	Focus Area	Industry	Niche Opportunities
CCAM	Advanced Manufacturing Systems	Advanced Manufacturing, Aerospace, Transportation, National Security, Energy	Advanced manufacturing applications
	Surface Engineering	Advanced Manufacturing, Aerospace, Transportation, National Security, Energy	Advanced manufacturing applications
NASA LaRC	Aeronautics	Aerospace, Aviation	Aerosciences, structures and materials, systems analysis, engineering and safety
	Atmospheric/Earth Sciences	Life Sciences, Aerospace, Environment, Advanced Manufacturing	Remote sensing, measurement
	Space Exploration	Aerospace, Environment	Aerosciences, structures and materials, systems analysis, engineering and safety
	Space Operations	Aerospace	Aerosciences, structures and materials, systems analysis, engineering and safety
NIA	Nanotechnology	Aerospace, Advanced Manufacturing, Environment, Life Sciences	Boron nitride nano tube growth
	Systems Applications, Engineering	Aerospace, Advanced Manufacturing, Environment, Life Sciences	Uncertainty quantification
Dahlgren	Chemistry/Biology	Advanced Manufacturing, National Security	Detection, decontamination
	Complex System Architecture	National Security	Large-scale systems and systems architecture
	Directed Energy	National Security	High-power lasers
	Distributed Systems	IT, Communications, National Security	First response to catastrophic events
	Electromagnetic Environments	National Security	Topside design, spectrum management
	Human Systems Integration	National Security	
	Meta-materials/	National Security	Topside design,

	Nanomaterials		advanced materials for RF applications, advanced sensors
	Network Analysis	IT, Communications, National Security	First response to catastrophic events
	Sensors	National Security	Radar, electric optical, infrared, and quantum sensor systems
	Software Intensive Systems	National Security	Software design, development, and testing
	Surface Weapons Technology	National Security	Surface weapons technology
	Unmanned Systems	National Security	Port security
SRI SV CADRE	Biomarker Discovery (Proteomics)	Life Sciences	Biotechnology, pharmaceuticals, biosciences
	Global Health/Infectious Diseases	Life Sciences	Biotechnology, pharmaceuticals, biosciences
	Metabolic Diseases (Diabetes)	Life Sciences	Biotechnology, pharmaceuticals, biosciences
Jefferson Lab	Accelerator Science	Life Sciences, Energy	Nuclear medicine, nuclear energy
	Applied Nuclear Science and Technology	Energy, Environment	Novel energy technology, chemistry, and materials research
	Nuclear Physics	Energy, IT, Environment	
	User Facilities/Advanced Instrumentation	Life Sciences, Advanced Manufacturing	Semi-conductor, pharmaceuticals

APPENDIX F: Research and Technology Investment Advisory Committee (RTIAC)

Designated in Legislation

Research University: Dr. Dennis Manos, Vice Provost for Research and Graduate/Professional Studies – College of William and Mary
Research University: Dr. John Noftsinger, Vice Provost for Research and Public Service – James Madison University
Research University: Dr. Mohammad Karim, Vice President for Research – Old Dominion University
Research University: Dr. Thomas Skalak, Vice President for Research – University of Virginia
Virginia Economic Development Partnership: Mr. Martin Briley, President and CEO

Citizen Members

Venture Capital: Mr. Bobby Ocampo, Associate – Grotech Ventures
Venture Capital: Mr. Robert Patzig, CIO – Third Security
Engineering Firm: Mr. Daniel Gonzalez, Principal – Avison Young
Research Facility: Dr. Robert Kahn, Chairman, CEO, & President – Corporation for National Research Initiatives (CNRI)
Technology Company: Mr. Thomas Kirchmaier, Senior Vice President/General Manager Intelligence Solutions – General Dynamics Information Technology (GDIT)