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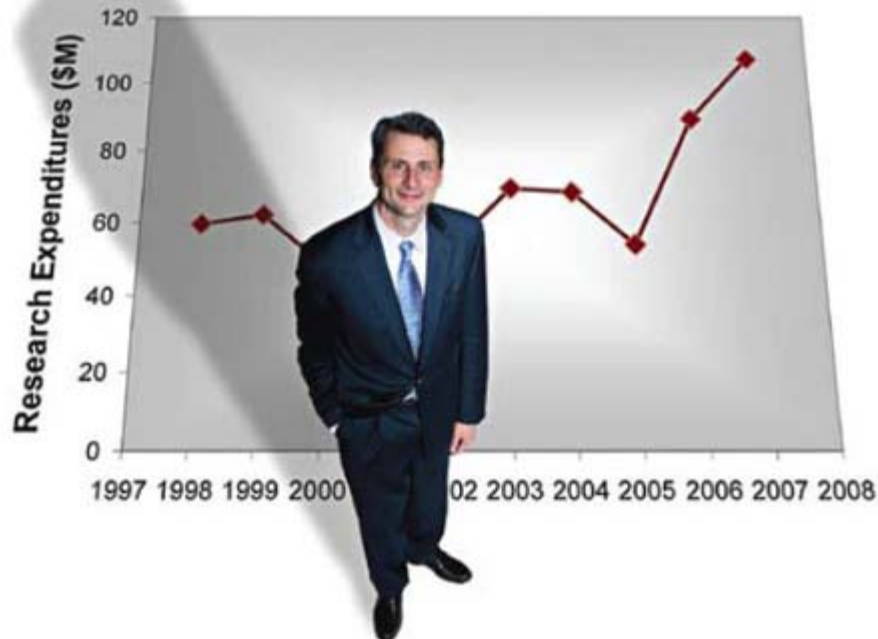
College of Engineering



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Research Expenditures



Introduction: Meet the Commonwealth's Leading College of Engineering, Virginia Tech's Backbone

By all measurements, Virginia Tech is the highest ranked research university in the Commonwealth of Virginia. The February 2008 listing of the top research institutions by the National Science Foundation (NSF) and the amount each one spent on research and development in the 2006 fiscal year (the most recent year for which the statistics currently exist) show our university 54th with \$322 million. The next Virginia university on the list is the University of Virginia at number 72 with \$238.8 million in research.

The College of Engineering at Virginia Tech reported over \$107 million in research expenditures to the American Society of Engineering Education as part of its 2007 survey of research universities for *US News and World Report*. Furthermore, in its most recent survey (FY 2006) of total engineering research expenditures at universities and colleges, the National Science Foundation ranked the Virginia Tech College of Engineering 11th in the nation. This marks a steady improvement since the FY 2003 survey, when the college was ranked 13th in the nation.

Again, these statistics, as well as other reputational rankings, show Virginia Tech's College of Engineering is the leader among its peers in Virginia and one of the finest colleges of engineering in the nation.

This second NSF survey also shows that the College of Engineering represents more than one-third of the university's total research expenditures. Yet our 336 faculty members in 2006 (352 in 2007-08) represented only some 25 percent of the total number of faculty at the university (1,360 for fall 2006).

By all standards, Virginia Tech's College of Engineering plays a prominent role within the university, the state, and the nation.

The following articles about our enduring and emerging research strengths represent just a sampling of our success stories. When we reflected on the past 30 to 40 years of achievements of our engineering faculty, it was no surprise to know they were leading their fields in the late 1960s and 70s, and they are still doing so today.

As examples, Roe-Hoan Yoon's three decades of work in mining and minerals engineering resulted in his induction into the National Academy of Engineering this year. And Charles Bostian of electrical and computer engineering was winning research awards in the late 1960s in satellite communication, and during this past year advised the student group that won the international smart radio challenge.

The materials group has two members of the National Academy of Engineering, Ken Reifsnider, professor emeritus, and James McGrath. The state began investing in Reifsnider's work in the 1980s, recognizing him as the leader of the statewide efforts in materials systems, and the NSF supported McGrath and his colleagues, establishing its high performance materials center at Virginia Tech.

With our emerging strengths, such as Space@VT, our colleagues have overcome significant competition from well-entrenched research groups at other universities and attracted highly sought-after research dollars and recruited renowned scholars.

We hope you will find this edition conveys the excitement and enthusiasm of our award-winning faculty who are contributing in leadership roles to the scientific and technological future. As Virginia's Gov. Timothy Kaine said recently, "The most precious asset in the world...is brainpower," and bringing Virginia Tech's College of Engineering to the table at virtually every economic development opportunity is key. His remarks came after he successfully negotiated locating a Rolls-Royce manufacturing facility in the commonwealth, using, in part, the strengths of the Virginia Tech and U.Va. engineering colleges to finalize the arrangements.

"This Rolls-Royce deal is a bellwether of things to come," Kaine concluded, and Virginia Tech's College of Engineering remains ready to help ensure our state and nation's scientific and technological advantage.

*Don Leo, Associate Dean
Research and Graduate Studies*



Jeff Reed, who holds the Willis G. Worcester Professorship, joined the wireless efforts at Virginia Tech in its infancy.

Wireless@VT

Technologies used today by companies, such as Direct TV and Globalstar, are based on satellite communications efforts started here four decades ago.

"Rome wasn't built in a day" is the adage that comes to mind when you ask Jeff Reed, director of Wireless@VT, about this highly successful, comprehensive research endeavor. In an interview in 2008, he still refers back to the 1960s when the late Professor Herb Kraus of the electrical engineering (EE) department "got things going" in the radio circuits area. Then, EE professors Charles Bostian and Warren Stutzman arrived in 1969, and they worked as a team, emphasizing satellite communications and electromagnetic wave propagation.

"Their work was the basis for the technology" that companies like Direct TV, Iridium Satellite, and Globalstar were based on, Reed says. Beginning with their first NASA-funded project in 1971 and continuing through the 1990s, Bostian and Stutzman led Virginia Tech's satellite communications efforts, building ground stations for global satellite communications and characterizing the propagation environment. "The work they started (as members of the Satellite Communications Group) impacted standards and real systems used by industry and government," Reed recalls. In the past four decades, several successful research groups emerged at Virginia Tech, each with overlapping research interests. The Antenna Group, the Mobile and Portable Radio Research Group (MPRG), and the Center for Wireless Communications (CWT) were among the most visible, and today they continue to function, but Wireless@Virginia Tech now pools the various resources. It is the result of a funding investment by the interdisciplinary institute for Critical Technology and Applied Science (ICTAS) at Virginia Tech.

Some of the technologies developed by the wireless researchers at Virginia Tech in the 1990s include SIRCOM, CELLSCOPE, SMT, Stallion, and Interactive Video.

The MPRG was founded by Ted Rappaport two years after his arrival in 1988, and Brian Woerner and Reed were recruited to its faculty in 1990 and in 1992, respectively. "It was the first research group devoted to modern wireless communications, such as cellular communications," Reed recalls. "We had 20 students and were in three offices where the monitors were so close that when one person entered something on a keyboard, it showed up on the next person's monitor as a blip," Reed laughs. But in these crowded conditions, Rappaport was still able to write the first textbook on the subject, called *Wireless Communications: Principles and Practice*. An instant classic in academia, some 30 universities from around the world had adopted its use within the first 12 months. A defining moment for the wireless researchers came when they started receiving major funding from the Defense Advanced Projects Research Project Agency (DARPA). For one proposal, "we (Rappaport, Woerner, and Reed) stayed up for three nights, working off one laptop while we were in New Jersey for a meeting. We did not have a printer that was compatible, so we had to drive for an hour-and-a-half to find one. It was so beyond being rational," Reed smiles today. But the insanity paid off, and they were awarded the \$1.7 million DARPA contract to develop a revolutionary approach to wireless communications.

This started a long-standing relationship between Virginia Tech and DARPA in wireless communications. Specifically, the 1993 DARPA grant asked the Virginia Tech engineers to combine new technologies in computer chips, antennas, and digital signal processing in a novel way, eventually allowing wireless devices to be extremely miniature, but able to adapt to interference in the radio channel. They accomplished their goals and increased the number of radio devices that could share a single radio frequency, thereby increasing the capacity of wireless users in a specific region of space. "Companies spun out of this research," Reed says, including the first wireless communications company in Blacksburg, TSR Technologies, which later was sold to Grayson Electronics. In 1998, a second spin-off, Wireless Valley Communications Inc., was founded and later sold to Motorola for some \$30 million. "People made their careers from the enabling technologies that we developed," Reed says. In the 1990s, the wireless researchers at Virginia Tech began filing for patent after patent. Within a few years, some of the technologies they had developed included SIRCoM, an indoor channel modeling program; CEIISCOPE, a technology that identifies a person using a cellular phone; SMT, a site modeling tool for indoor communications that led to Wireless Valley Communications; Stallion, a high-performance computing device for handsets; and interactive Video, a wireless mechanism for users to order products they see advertised on TV. All were available for licensing through Virginia Tech Intellectual Properties Inc.

In one of the first highly publicized uses of CEIISCOPE, the FBI employed it in 1995 to track down Kevin Mitnick, the nation's most-wanted computer hacker, in Raleigh, N.C. The SMT software was licensed in its introductory year to leading communications companies, including Motorola, Ericsson, Hewlett Packard, Tellans, and Mobile System International. Some of the other wireless projects the different groups were working on then are commonplace today, such as the creation of Bluetooth technologies that enable the wireless office emerging in the 21st century; software radio for wireless communication interoperability and smart antenna technologies to eliminate co-channel interference; and advanced wireless modems to support remote computing and high-data-rate wireless access to the internet. They also were instrumental in improving cellular communications to prevent co-channel interference, and in allowing radio waves to penetrate into buildings. In the area of intelligent transportation systems, they were working on Global Positioning Systems more than a decade before they became popular Christmas presents for directionally challenged drivers.

Wireless@VT graduate students took top honors in the Inaugural Smart Radio Challenge at the 2007 Software Defined Radio Forum conference in November. Tech was the only school with two teams among the final 10 competitors. One of the teams won the Grand Prize and the other won the Best Design Prize.

Additional seed money was invested in wireless research at Virginia Tech in 1993, with the Virginia Center for Innovative Technology establishing a Technology development Center for Wireless Telecommunications Systems. Bostian was named the first director of this effort.



Today, Jeff Reed directs Wireless@VT and continues to develop revolutionary approaches in the field of wireless communications.

In 1995, William Tranter, the Schlumberger Professor of EE at the University of Missouri-Rolla, decided to spend a sabbatical with the wireless group, and afterward joined the Virginia Tech faculty. He brought with him a National Science Foundation support grant to develop revolutionary courses for seniors and graduate students in the wireless communications area. This effort resulted in a number of popular textbooks in wireless communications.

MPRG secured a larger DARPA grant in 2000 in collaboration with the Massachusetts-based Raytheon Company, a worldwide leader in electronics for defense and information systems. They shared in a \$15 million contract to develop advanced technologies. Virginia Tech's portion was called Airborne Communications Node (ACN), to be used in military communications strategies. Researchers helped develop the ACN payload that acted as a surrogate satellite, relaying voice and data communications among ground forces, enabling them to communicate well beyond line-of-sight.

As the wireless faculty moved into the 21st century, Virginia Tech became the leading research institution in the field of cognitive radios, called a new frontier for the world of wireless communications. Cognitive radios are intelligent radios that can determine the best way to operate in any given situation. "The new cognitive radios are similar to living creatures in that they are aware of their surroundings and understand their own and other users' capabilities and the governing regulatory constraints" and address the incompatible communications problems between emergency services, says Bostian, also an Alumni distinguished Professor (ADP). They also hold promise for rapid deployment of emergency communication infrastructure in the event of a disaster. ICTAS has played an important role in helping to develop this new technical thrust and establishing Tech's dominance in this research area.

When Reed considers the most recent successes for the comprehensive wireless research groups at Virginia Tech, he again points to

Bostian's work, saying his advisorship of the team of graduate students who took top honors in the 2007 International Smart Radio Challenge shows just how versatile he is. "He made a huge impact early in his career, and 40 years later he is still making huge technical advances that not even a science fiction writer could have conceived of 40 years ago," Reed says. "It shows what a good researcher he is and how he has evolved with the time."

Reed also points to Stutzman's recent successes in WiFi, a wireless internet connection. Stutzman and his graduate student at the time, Michael Barts, invented an antenna for WiFi that allows users to receive signals in remote locations, such as airports and hotels. Recently, the cities of Bologna, Italy, and Perth, Australia, went completely wireless using the antenna. The research for the antenna took five years and it became commercially available in 2000.

Wireless@Virginia Tech currently has more than 30 faculty members whose technical expertise ranges from communications to networks, and more than 100 graduate students focused on wireless. While expertise lies deep within electrical engineering, such as antenna design, wireless networking, communication systems, micro-electronics, RF electronics, and system integration, disciplines outside of electrical engineering, such as computer science, mathematics, economics, and business, also make up its team.

By Lynn A. Nystrom

FACTS AT A GLANCE

A Brief History

Officially launched in June 2006 with seed money from the university's Institute for Critical Technology and Applied Science (ICTAS), Wireless @ Virginia Tech (W@VT) brings together researchers, facilities, equipment, and expertise from many disciplines throughout the university to create a comprehensive solution for wireless challenges.

One of the largest university wireless research groups in the United States, W@VT encompasses numerous centers, groups, and laboratories, including the world-renowned Mobile and Portable Radio Research Group, DSP Research lab, Wireless Microsystems Lab, Center for Wireless Telecommunications, VLSI for Telecommunications, and Virginia Tech Antenna Group. The research group consists of more than 30 faculty members whose technical expertise ranges from communications to networks, and more than 100 graduate students focused on wireless.

Research Team:

35 full-time faculty members. For a complete listing, see www.wireless.vt.edu/people.html.

Number of patents held by wireless researchers: U.S. patents issued-17; U.S. patents pending-10; foreign patents issued-9; foreign patents pending-11; provisional applications-16; registered copyrights-7; trademarks-2.

Educational component:

Several new courses have been developed in the areas of communications, signal processing, antennas, and software defined radios. Wireless@VT faculty have authored or co-authored over 20 textbooks and contributed chapters in more than 30 textbooks.

Publications:

More than 200 journal papers and in excess of 300 conference papers.

Economic value of the groups over 20 years:

A conservative estimate of research expenditures is \$2 million a year for the whole group, or approximately \$40 million over the past 20 years.

Current affiliate members:

- Analog devices
- Applied Signal Technology
- Army Research Office
- Digital Receiver Technology
- DRS Technologies
- E.F. Johnson
- Qualcomm Inc.
- Raytheon IIS
- Rockwell Collins
- Samsung Telecommunications America
- Sharp Labs of America
- Syracuse Research Corporation
- Thales Communications
- Tyco Electronics
- Technology Transfer

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Center for Power Electronics Systems (CPES)

The paradigm shift in the manufacturing of power electronics products had its origins in Blacksburg.



Fred Lee, who holds the Lewis A. Hester Chaired Professorship, directs the premier power electronics program at a research university in the country, the Center for Power Electronics Systems. Lee believes advances in power electronics can reduce the world's electric power consumption by 30 percent.

Some 12 years ago, Intel, a multibillion-dollar global company that increased its operating revenue by some 45 percent in 2007 alone, became such a fan of Virginia Tech's Fred Lee and his power electronics center that it asked his help in developing the next generation computer processor. By 2000, every Intel processor used a revolutionary power supply source, known technically as a multi-phased voltage regulator module (VRM) that Virginia Tech helped to develop.

Today, Lee says all manufacturers of computer processors use the multi-phased VRM concept. The reason is the VRM concept is modular and scalable, allowing quick adaptation to the fast processor development with ever-increasing demands in data processing speed and power consumption. Furthermore, the solution enables the manufacturers of power electronics products to use more economical automated processes as opposed to the conventional custom design that necessitates a longer, costlier planning time.

"This particular technology has enabled the U.S. power electronics industry to continue maintaining its leadership role in both technology and market positions. It has enabled new job creation and job retention in the U.S. Without this technology infusion from the premier power electronics program in the nation, CPES (Center for Power Electronics Systems, directed by Lee), the U.S. power electronics industry would have lost its market position to overseas low-cost providers in providing the power management solutions to the new generation of microprocessors," according to a 2007 Virginia Tech report highlighting this achievement.

To the average person, this type of technological improvement that breaks a typically complicated power processing solution and replaces it with modular building blocks with a highly integrated solution had many consequences. It represented the beginnings of a paradigm shift in the manufacturing of power electronics products--including motor drives for heat pumps, air conditioners and other industrial and commercial applications. Also, power electronics is integrated with the microelectronics business, now Virginia's largest industry. "Almost everything a consumer touches has power electronics in it," Lee says. "It's really an enabling technology that is not visible."

Virginia Tech led a team of three universities on a \$3.2 million Office of Naval Research project to develop power electronics building blocks (PEBBs), standardized forms of power electronics components including semiconductor materials, circuits, controls, sensors, and actuators. It made PEBBs lightweight, energy and cost efficient, and customized.

"We are changing the way electricity is used," he says. For example, if data centers, which use enormous amounts of energy, can be redesigned from the current AC distributed system, using off-the-shelf equipment, to a new power system architecture based on high-voltage DC systems, an initial study shows the efficiency could be improved some 10 to 20 percent. Web giant Google claimed that every one percent improvement in the efficiency of the data center means a \$1 million savings in electrical energy bills, according to Lee.

"The long term health of the U.S.'s power electronics industry has been of increasing concern with the migration of the manufacturing base to Asia. Most of the power electronics industries are bottom-line focused and emphasize development rather than research," Lee says. "When they can spend 80 cents per hour versus \$18 an hour per employee," industry did not have the motivation to improve the technical aspects of the manufacturing process.

But with globalization and the cyclical events in the economy, often attributed to the cost and heavy use of energy, the need to produce a savings in future power consumption becomes of paramount importance to every type of consumer and supplier, including the manufacturing industry.

CPES researchers used the knowledge gained while designing the VRM to develop an integrated approach to power electronics systems. What they envisioned was analogous to a set of standardized toy building blocks (lego). They would develop integrated power electronic modules (IPEM) as the basis for their new system approach. CPES' IPEM solution is based on the integration of a new generation of devices, innovative circuits, and functions. Similar to building blocks, IPEMs could then be customized and integrated into various solutions for specific needs.

The satellite power system for NASA's Mission to Planet Earth, monitoring ozone depletion and carbon dioxide buildup, was designed in part by members of the Virginia Power Electronics Center (VPEC), the predecessor to CPES.

"We started the concept of integrated solutions," Lee says, "and it is now a multibillion dollar industry."

For example, CPES researchers have patented numerous power electronic improvements, such as converters for hybrid fuel cells used in electric vehicles. They also hold several patents that can effectively reduce switch voltage stress and switching losses, known as zero-voltage switching and zero-current switching techniques. These underpinning technologies significantly reduce switching losses and stresses and form the basis for today's high-frequency power conversion technologies widely used in the IT industry, as well as aerospace, consumer, and industrial applications.

As with the VRM technology, other companies have introduced systems similar to CPES' IPEM, and the similar products are used to power the new generation of computers, telecommunications, and network equipment products.

As CPES emerges from its NSF sponsorship, it is expanding its research mission beyond the power delivery and power management for the computer, telecommunication, and motor drives industries. It is looking at efficient power management for small hand-held equipment, such as cell phones, PDAs, laptop/desktop computers, and to power architecture for such high power systems as data centers, more electric ships and aircraft systems. The center has set aside \$1 million in the past two years to explore emerging power electronics technologies and applications using the future sustainable home as a platform to demonstrate potential energy savings and energy sustainability based on renewable energy sources.

At the end of 10 years, CPES researchers have produced 59 promising emerging technologies that are at various degrees of technology transfer. Among them are the powering of a new generation of microprocessors, technologies for the integration of such power electronics components as circuits and sensors, and the custom-designed integrated components for standardized methods of assembling power converters.

"It's an old argument," Lee smiles. "Thomas Edison wanted DC but Westinghouse wanted AC. Well, we want to promote the DC voltage in energy-sustainable buildings."

Specifically, CPES researchers hope to design a future sustainable home that has load integrated power processors powering such loads as lighting, HVAC systems, entertainment, and data systems. The center advocates source-integrated power processors, which integrate power converters with solar photovoltaics on the roof and a dedicated wind turbine. The house would also have a bidirectional converter for a plug-in hybrid vehicle and for a grid connection.

Lee says he hopes that a "living lab" representative of a future sustainable home will be on the Virginia Tech campus soon.

VPEC members designed a new technique based on an electronic circuit scheme that accommodates higher switching frequencies and eliminates power losses due to switching. The result is a reduced demand for electric current and a greater efficiency of power supply.

By Lynn A. Nystrom

FACTS AT A GLANCE

A Brief History

Fred Lee arrived at Virginia Tech in 1977 and immediately started a program in power electronics. By 1982, he founded the Virginia Power Electronics Center (VPEC). In 1987, the Virginia Center for Innovative Technology (CIT) created the Technology Development

Center for Power Electronics, starting Virginia Tech's power electronics research efforts. The seed money led to the development of key power electronics technologies for a wide range of industrial applications. In the subsequent years, CIT funds were used mostly for technology transfer and technical support to Virginia companies.

VPEC was instrumental in attracting delta Power Electronics lab to the Corporate Research Center in Blacksburg. VPEC also provided support to IBM in Manassas, GE drive Systems in Salem, and Inland Motor/industrial drives in Radford in their conversion from military to commercial products. In the 1990s, it offered assistance to more than 30 companies in Virginia, including a VPEC spin-off company, VPT inc., in Blacksburg.

In 1998, VPEC morphed into the Center for Power Electronics Systems (CPES) and became Virginia's first National Science Foundation Engineering Research Center (NSF ERC). Founded as a University/Industry coalition to help resolve the nation's power problems, Lee, now a University Distinguished Professor, continued to direct the CPES consortium, and Dusan Boroyevich, also an electrical and computer engineering professor at Virginia Tech, became the co-director. Virginia Tech's ERC university partners are North Carolina A&T University, University of Puerto Rico at Mayaguez, Rensselaer Polytechnic Institute, and the University of Wisconsin. The NSF renewed CPES' funding in 2004 after a successful sixth year review of its projects. As was planned from the inception of CPES, funding from NSF ends in 2008, and the center's 87 industrial partners with the university consortium will become dominant.

CPES Research Team:

32 faculty and 5 research staff

Educational Component:

105 Ph.D.s, 181 master's, and 96 bachelor's degree minors in power electronics area awarded

Publications:

More than 1,600 technical papers, theses, and dissertations

Economic Value of the ERC Over 10 Years:

- \$30.4 million from NSF
- Approximately \$7.5 million in matching cost share funds from the university and state
- Approximately \$9.4 million in industry membership support
- Approximately \$29 million in sponsored research from industry, government, and institutions

Technology Transfer:

50 patents, 131 invention disclosures, 331 licenses issued by VTIP

Outreach to industry:

60 short courses and workshops held, 149 industry internships by CPES students

FACTS AT A GLANCE

Industrial Affiliates

Principal Member Plus

ABB Inc. - Corporate Research*
Analog Devices+
Crane Aerospace & Electronics+
Delta Electronics+
FSP Group Inc. +
GE Global Research*
Hipro Electronics Co. Ltd.+
Infineon Technologies+
International Rectifier*
Intersil Corporation+
Linear Technology+
Lite-on Technology Corporation+
MKS Instruments Inc.*
Monolithic Power Systems+

Principal Member

DRS Power and Control Technologies Inc.
Eaton Corporation - . Innovation Center
Eltek Valere
Emerson Network Power Co. Ltd.
Groupe SAFRAN
HR Textron, Textron Systems Corporation
Maxim . Integrated Products
Rockwell Automation - Allen-Bradley
SEW EURODRIVE GmbH & Co. KG
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Hitachi Computer Peripherals Co. Ltd.
Intel Corporation
Johnson Controls
KEMA Inc.
L-3 Communications, Power Paragon Ind.
Microsoft Corporation
NetPower Technologies Inc.
Nippon Chemi-Don Corp.
Northrop Grumman
OSRAM SYLVANIA Inc.
Panasonic Electric Works Laboratory of American Inc.

Murata Power Solutions+
National Semiconductor Corporation+
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Primarion Corporation+
Renesas Technology Corporation+
Richtek Technology Corporation+
Rolls-Royce*
Texas Instruments+
The Boeing Company*

Schneider Toshiba Inverter Europe
Semikron International GmbH
Shindengen Electric Mfg. Co. Ltd.
Toyota Motor Corporation

Affiliate Member

ABB. Inc., Drives & Power Products Div.**	Hamilton Sundstrand**	Pacific Scientific EKD**
Ansoft Corporation	Hoganas AB**	Phoenix International**
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Cree Inc.**	Kohler Company**	S&C Electric Company**
Curtis Instruments**	LEM USA . Inc.**	Schneider Electric - Square D**
Danfoss Drives**	Magnetek . Inc.**	TECO Westinghouse**
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Electronic Concepts inc.	Milwaukee Electric Tool Company**	Trane Company**
Emerson Electric Company**	MPC Products Corporation**	Transim Technology
Ford Motor Company**	MTS Systems Corporation**	Unico Inc.**
Fuji Electric Advanced Technology Co. Ltd.**	Nissan Motor Co. Ltd.**	United Technologies Research Center**
GE Energy**	Oak Ridge National Laboratory**	VPT Inc.
GM Advanced Technology Center**	Oshkosh Truck Corporation**	Whirlpool Corporation**
Grundfos A/S**	Otis Elevator Company**	Yaskawa Electric America Inc.*

+ Power Management Consortium (PMC) Members
* Industrial Fellowship Sponsors
** WEMPEC Members

Center for Advanced Separation Technologies (CAST)

Southwest Virginia is showing the world how to burn coal more cleanly and reduce emissions.



Roe-Hoan Yoon, the Nicholas T. Camicia Professor of Mining and Minerals Engineering, developed a coal and mineral recovery process that is now marketed worldwide by two international companies through license agreements with Virginia Tech.

Almost 30 years ago, Virginia Tech engineering researchers Roe-Hoan Yoon, Gerald Luttrell, and Gregory Adel received a grant from the University Coal Research Program, U.S. Department of Energy (DOE), to develop a method of recovering fine coal particles dispersed in water. The coal fines are produced during the process of mining coal and cleaning (or washing) it in water. The three researchers had proposed to DOE that they could recover the coal fines using small air bubbles, called "microbubbles."

Their research effort resulted in a commercially successful technology, which is being marketed under the trade name Microcel flotation column. Although it was developed originally for coal companies to recover fine coal from waste streams, the technology is now used in both the coal and minerals industries. Two companies, Metso Minerals and Eriez Manufacturing, are marketing them worldwide under license agreements from Virginia Tech. It took a while, however, for the technology to achieve the worldwide prominence it has today.

Eriez has hired four doctoral graduates from Virginia Tech who had been trained on the Microcel technology. The expertise and scientific background they acquired during their studies at Tech were instrumental in bringing the technology to the marketplace. Mike Mankosa, Class of 1983, is now serving as the vice president of operations, and has recently received the outstanding Alumni Award from the mining and minerals engineering department for his achievement.

During the past 10 years or more, Yoon and his colleagues have been developing advanced dewatering technologies. Because the coal is washed in water during the Microcel process, it is necessary to remove the water before shipping and utilization. One of the advanced dewatering technologies involves specialty chemicals that can be added to various vacuum or pressure filters. It is licensed to Nalco, a \$3.5 billion company, for worldwide distribution. Steve Abbatello, Class of 1982, is responsible for this activity as the strategic business unit leader of the Global Mining and Metals division of Nalco.

In 2007 Roe-Hoan Yoon, the Nicholas T. Camicia Professor of Mining and Minerals Engineering in the College of Engineering at Virginia Tech, received one of the highest honors awarded by the Society for Mining, Metallurgy, and Exploration. The Robert H. Richards Award in Minerals Processing was presented to Yoon, recognizing him for his metallurgical research in advancing the surface chemistry of mineral systems, cleaning and dewatering coal, developing flotation kinetic models, and designing new minerals processing technologies, as well as for his dedication to high-quality engineering education. In 2008, he was elected to the National Academy of Engineering, the highest honor for an engineer.

To facilitate the marketing and sales of the specialty chemicals, Nalco opened a laboratory at Virginia Tech's Corporate Research Center and hired two of Yoon's former Ph.D. students and two undergraduate students as co-op students. "Industry needs the high-tech trainee to understand the value of the technology and to be able to transfer it properly to the industry," Luttrell explains.

It appears that advanced separation technologies developed by Yoon and his colleagues at Virginia Tech will also be used in developing countries like India and China to reduce the emission of CO₂ the major green house gas (GHG). As part of the Asia-Pacific Partnership on Clean development and Climate (APP) program, the U.S. Department of State (DOS) is funding Virginia Tech to help India burn coal more cleanly and reduce CO₂ emissions in coal-burning power plants. Also, Yoon has submitted a proposal to Coal India limited (CIL), which produces 86 percent of coal in the country, to implement the advanced fine coal cleaning technologies in a demonstration plant.

A university-industry team led by the Center for Advanced Separation Technology at Virginia Tech was awarded in excess of \$1 million in 2007 by the U.S. Department of State to help India reduce carbon dioxide (CO₂) emissions by developing low-cost technologies for cleaning coal.

The most exciting offshoot to the technology development may lead to a leap in science. Yoon is expounding upon his effort to prove the existence of the large attractive force between hydrophobic substances, such as coal, placed in water. As the force is observed only between hydrophobic surfaces, it is referred to as hydrophobic force, naturally. It was first reported in *Nature* by Professor Jacob Israelachvili of the University of California and Professor Richard Parshley of Australian National University in 1982. However, its scientific origin is still not known, and many scientists argue that it is due to artifacts. Yoon believes it is real.

The difficulty in accepting the existence of hydrophobic force for many scientists lies in the fact that the attractive force is detected at relatively large distances, with up to 60 to 80 nanometers (nm) separating two hydrophobic surfaces. (one nm is one millionth of a millimeter.) Some researchers suggested that the hydrophobic force was created by the nano-sized air bubbles existing on hydrophobic surfaces, which has recently been disproved by Yoon and his colleagues at Virginia Tech in a scientific publication.

Yoon believes that the new attractive force originates from the tendency of water molecules to re-orient themselves around hydrophobic surfaces. "Understanding the basic sciences involved will have far-reaching consequences in engineering and science." Further, all of the fossil energy resources, such as coal, oil, natural gas, bitumen in oil sands, kerogen in oil shale, and methane hydrate, are more or less hydrophobic. "Therefore, understanding the nature of the hydrophobic force will help exploring and utilizing these resources efficiently and in a manner that can improve the environment," Yoon says.

Yoon and his graduate students used the hydrophobic force in mathematically modeling the process of coal particles being collected by air bubbles during flotation, which is one of the most important separation processes used in the minerals and coal industries. FLSmidth, the largest flotation machine supplier in the world, is funding the project to further develop the model for optimal design and operation of new flotation machines.

In addition, Yoon can also explain the formation of methane hydrate in ocean floors and permafrost using the improved understanding of basic sciences involved in the hydrophobic interaction. Methane hydrate refers to the methane (CH₄) molecules encapsulated in ice crystals, and is dubbed as "the ice that burns." The amount of methane, the cleanest form of fossil fuel, present as hydrate in the world amounts to 400 million trillion cubic feet (tcf), which is 73,000 times larger than the conventional natural gas resource, and is larger than all fossil energy resources combined.

"On the other hand, methane is a 21-times more potent GHG gas than CO₂," Yoon says. "Therefore, we are better off to recover and utilize it." According to the U.S. Geological Survey (USGS), the Blake Ridge deposit off the shores of the Carolinas alone has approximately 1,300 tcf of methane as hydrate, which is more than six times larger than the total conventional natural gas reserves left in the U.S. He points out that Virginia Tech has the largest and closest mining school to this enormous resource.

Yoon is pleased that he has recently received significant funding from the U.S. Department Energy to expand his hydrate research. As part of this, his group is exploring the possibility of separating different gasses, such as CO₂ and nitrogen, from each other by selectively forming gas hydrates.

"Success of the new program will help increase the availability of low-cost energies to sustain economic growth, prosperity, and way of life. Furthermore, the long-term, high-risk research projects based on fundamental research will serve as vehicles for training students to become future leaders in industry and academia," Yoon says.

It took a long time for Yoon's microbubble flotation concept to achieve commercial fruition, so the quest to explore the largest known energy source of methane hydrate needs to begin now — with Yoon's call for increased support from the federal government and industry.

By Lynn A. Nystrom

FACTS AT A GLANCE

A Brief History

A member of the Virginia Tech mining and minerals engineering faculty since 1979, Roe-Hoan Yoon received seed money from Virginia's Center for Innovative Technology (CIT) in 1988 when it was announced that the Center for Coal and Minerals Processing would be housed at Virginia Tech. In a CIT newsletter, it said it was funding the new center "to provide badly needed research in the mining and minerals processing industry, with an ultimate goal to foster the commercial application of advanced coal cleaning technologies." The CIT eventually named the center one of its Technology development Centers (TDC), citing its growing list of industrial sponsors, diversification into other areas of processing and characterization of particulate materials, and commercialization of the microbubble flotation technology.

In 2001, Virginia Tech and West Virginia University received a \$3 million award from the U.S. Department of Energy (DOE) to establish the Center for Advanced Separation Technologies (CAST) to conduct fundamental research in the area of advanced separations. Yoon was named its director. In 2002, five additional universities joined CAST and formed a consortium to conduct crosscutting advanced separations research that can benefit the coal and minerals industries across the country. The new members of the consortium were Montana Tech, University of Utah, University of Nevada, New Mexico Tech, and the University of Kentucky.

In 2005, CAST received \$12 million from the U.S. DOE's National Energy Technology laboratory to advance separation technologies used by mining industries in order to meet national energy and environmental goals.

CAST Research Team:

30 faculty and 16 research staff

Number of Patents held by CAST researchers:

14

Educational Component:

14 Ph.D.s, 39 master's degrees awarded through CAST

Publications:

More than 265 technical papers, theses, and dissertations

Economic Value of CAST Over 30 Years:

Almost \$15.3 million from the Department of Energy \$1.5 million in research contracts from industry, government, and institutional support

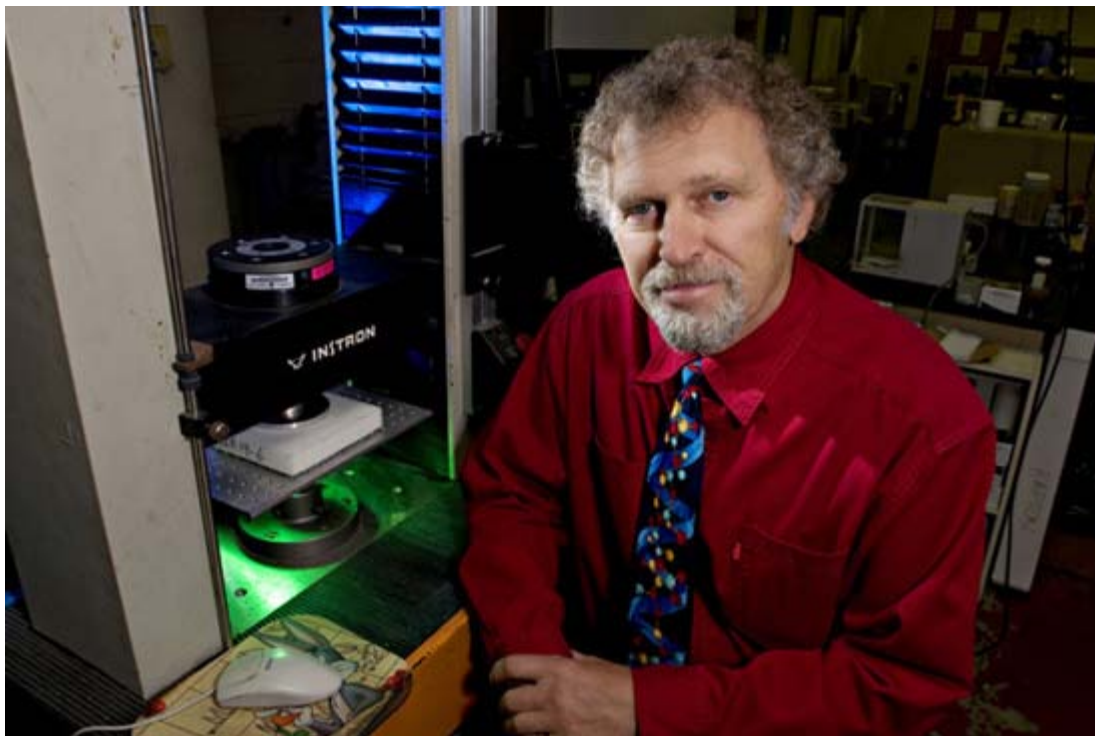
Industrial Affiliates:

45

Technology Transfer:

14 patents, 2 invention disclosures, five licenses granted to industry members

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For some four decades, Garth Wilkes, University Distinguished Professor Emeritus, has led research activities in the materials field. Today, his research has moved toward bio-based materials, including a biodegradable heart stent, nanotechnology, and green engineering practices.

Macromolecules and Interfaces Institute (MII)

A tale of two musicians led to an interdisciplinary partnership that spans polymers to bio-based materials.

For some four decades, Garth Wilkes, University Distinguished Professor Emeritus, has led research activities in the materials field. Today, his research has moved toward bio-based materials, including a biodegradable heart stent, nanotechnology, and green engineering practices.

In the 1970s, a tale of the friendship of two men began. Both were musicians by hobby, but their real vocations were as scientist and engineer. Their friendship and respect for each other started an educational partnership that has now spanned some four decades and helped to provide Virginia Tech with one of the best interdisciplinary materials programs in the world.

James McGrath's nameplate was nailed on a door of the Virginia Tech chemistry department, located in antiquated Davidson Hall, in 1975. Three years later, a young chemical engineer by the name of Garth Wilkes left his job at the Ivy League Princeton University to work in Randolph Hall, one of Virginia Tech's oldest engineering buildings. Together, they started the state-of-the-art Polymer Materials and Interfaces Laboratory (PMIL), the first true interdisciplinary research center that crossed college boundaries at Virginia Tech.

Following their lead, other chemists, like Tom Ward, Larry Taylor, and Jim Wightman joined PMIL, as did chemical engineers Don Baird and Richey Davis. Other disciplines gravitated toward the stimulating work on materials of the future. Dave Dillard of engineering science and mechanics (ESM) and Wolfgang Glasser of wood science and forest products were among the earliest cooperating faculty.

"We had the right administration to make this work," Wilkes says. "Paul Torgersen was dean of engineering and he told us to go for it. He nurtured our group, as did the then-dean of science, Henry Bauer. The timing was also good as Virginia Tech was looking for visibility in the late 1970s in the research area. With Jim and me as co-directors, science and engineering were co-owners across the campus. The key was that people held hands as a family, and we sold our work as one program."

When the Pilot Education Program of the Adhesive and Sealant Council, a consortium of more than 200 companies, looked for a center to conduct research for the council, it selected Virginia Tech's Center for Adhesive and Sealant Science (CASS).

Since PMIL's start in 1978, Virginia Tech scientists and engineers have excelled in polymer science and engineering. "Our product is and was the student who bridged several disciplines," Wilkes says. The scientists and engineers taught materials classes as a team, and one of the more visible components of their work was the short courses they offered through the American Chemical Society. Over the years, one course, Principles and Practices of Polymer Chemistry, was offered more than 166 times to some 5,000 researchers. "We started with the big boys," Wilkes smiles. The students were the men and women already working at such industrial giants as Shell, Mobile Oil, Exxon, Dow, and Dupont. Later, the swing went to smaller companies concentrating on biomaterials and nanotechnology.

Complementing PMIL's materials research, ESM Professor Hal Brinson organized the Center for Adhesion Science (CAS) and Ken Reifsnider founded the Center for Composite Materials and Structures (CCMS), both in 1982. CAS soon became the Center for Adhesion and Sealant Science (CASS). Researchers within the groups overlapped, and they were credited with numerous discoveries, such as the development of techniques to investigate damage states in composites — methods implemented in research labs around the world.

The commonwealth recognized the vast array of talent at Virginia Tech, saying its critical mass allowed for developing a world-class center, and so it established the \$1.3 million Virginia Institute for Material Systems (VIMS) at the university in 1988. VIMS encapsulated the work of the faculty of PMIL, CASS, and CCMS, as well as others across the state. By now, PMIL was already listed in the top five of its kind; CASS, the only such university-based center at the time, had a \$5 million endowment fund; and CCMS was rated number one in the country in terms of size and breadth of its composites activity with expenditures of more than \$2 million annually.

In 1989, the National Science Foundation (NSF) established the world-class center the state had thought possible — the NSF Center for High Performance Polymeric Adhesives and Composites (HPPAC) — at Virginia Tech. A 10-year multimillion-dollar venture, the investigators focused on creating materials advances for the aerospace industry during their initial work. Later, the researchers applied these innovations to a variety of other business sectors. Among numerous specific accomplishments, they prepared linear thermoplastics and toughened thermosetting materials and processed them into adhesives, prepregs, and composites, a first for a university facility. They demonstrated improved fracture toughness in composites. And they used a special technique to make carbon fiber composites and laminates. They improved the safety of manufacturing specific composites by eliminating the need to use solvents that were associated with flammability and pollution.

Since NSF center status is designed to last a maximum of 10 years, HPPAC dissolved in name by the turn of the century, but the interdisciplinary work continued. More recently, in 2004, this collaboration resulted in the formation of the Macromolecules and Interfaces Institute (MII).

MII represents the convergence of the three internationally known centers, as well as an institute and a graduate degree program. The participating institute in MII is the Materials Research Institute, also founded by McGrath in 1987. The graduate program is the interdisciplinary macromolecular science and engineering degree, approved by the State Council of Higher Education for Virginia in 2001 and directed by Judy Riffle of the chemistry department. Today, MII consists of about 20 faculty members, many of whom are new faculty, who are heavily involved in polymer, adhesion, and composite research, along with more than 30 additional faculty members involved in peripheral ways.

Dillard, a past director of CASS, spearheaded the efforts to bring the related areas under one university organization. "I wanted to take away the boundaries. Most of the faculty belonged to all five entities, and it was confusing where one organization stopped and another started," Dillard said.

Dillard credits Virginia Tech's extraordinary success in materials research to the personalities of some of its founders, many of whom are now retired or semi-retired. "Garth Wilkes, Jim McGrath, Hal Brinson, and Jim Wightman were all highly competent scholars who did things for the good of the group, and the university greatly benefited from their actions," Dillard says. In turn they recruited some very good people, he adds, "and we were able to provide the interdisciplinary academics better than most of our competitors. People as brilliant and famous as Garth and Jim took us under their wings, and we have a tremendous foothold in materials research based on what they established.

"Ken Reifsnider (now an emeritus ESM faculty member and a National Academy of Engineering (NAE) member who has moved his work to the fuel cell arena) laid the framework for the modeling of composites. At Virginia Tech, we are known for stress analysis," thanks to his initial efforts, says Dillard, who today holds the Adhesive and Sealant Science Endowed Professorship.

Materials research at Virginia Tech is now "morphing into the energy area. We have to solve the energy problem and its future contains a portfolio of energy solutions. Polymers are playing a big role in fuel cell development," Dillard says.

In other ongoing energy work, Dillard, Scott Case, and Michael Ellis, also engineering faculty members, are researching fuel cell membranes for General Motors. And McGrath has also moved in this direction, working with his group to improve fuel cell materials, specifically polymer-based proton exchange membranes. Visit www.research.vt.edu/energy/reshydro.html for a comprehensive overview.

"MII is well-positioned to be a leader in contemporary advanced materials growth themes of importance to the commonwealth," says McGrath, a member of the NAE since 1994 and a University Distinguished Professor. In addition to the fuel cell energy systems research, MII researchers continue work on high-performance adhesives and composites, novel biomaterials, and unique nanostructured materials and novel thin films.

Another part of MII's objective is to enhance economic opportunities within the region and the state through spin-off ventures, interactions with the Advanced and Applied Polymer Processing Institute in Danville, and other initiatives. Current research includes contracts with such companies as 3M, Avery Dennison, Battelle, Boeing, Daimler-Chrysler, Dow, DuPont, Hewlett-Packard, IBM, Johnson and Johnson, Luna, and NanoSonic.

"MII serves as a research engine. Building on our strengths and common interests, this organization is developing a program that can maintain and improve our national ranking from our current fifth place position in the last polymer materials survey done by *U.S. News & World Report*, positioning us for new funding opportunities in growth areas relevant to our expertise," Dillard says.

MII faculty includes members of the colleges of Agriculture and Life Sciences, Business, Engineering, Natural Resources, Science, and Veterinary Medicine. Directing MII is Richard Turner, a research fellow with Eastman Chemical Company's Polymer Technology Division, who joined Virginia Tech in January 2005. Turner, who holds more than 100 patents and was recently named the 2008 winner of the ACS Division of Polymer Chemistry's Industrial Polymer Scientist Award, earned his Ph.D. in organic polymer chemistry from the University of Florida, Gainesville, in 1971, followed by postdoctoral work in polymer chemistry in Darmstadt, Germany. He has worked in the research laboratories of Xerox Corporation, Exxon Mobil Corporation, Eastman Kodak Company, and Eastman Chemical Company.

With the wealth of talent in the materials field at Virginia Tech, the Army Research Laboratory (ARL) established the Multilayered Technologies for Armored Structures and Composites (MultiTASC) Materials Center of Excellence at the university in 2006 (www.mii.vt.edu/). Administratively positioned within MII, its purpose is to develop polymer-based materials to protect personnel and equipment against weapons attack. The center also offers graduate student and postdoctoral scholar mentorship and undergraduate research programs. It involves researchers from eight interdisciplinary research groups, two colleges, and six academic departments at Virginia Tech, who are teaming with personnel at the ARL Weapons and Materials Research Directorate. Tim Long of chemistry and Romesh C. Batra, ESM professor, are the co-technical directors.

The ARL award provides \$500,000 per year, potentially renewable for nine years, totaling approximately \$4 million. The Virginia Tech MultiTASC center researchers are developing structural materials with chemical resistance, thermal stability, and fracture resistance; transparent materials that are self-healing with anti-reflection and anti-abrasion surfaces; and new, efficient manufacturing processes to create multi-functional, multi-layered materials.

"The future of materials research is moving toward the bio-based materials, nanotechnology, and green engineering," Wilkes says. For example, he is working with a company on a biodegradable heart stent that is now in clinical trials. "It will do its job and then destroy itself," Wilkes explains. "We are also looking at the possibility of organic based light-emitting diodes. Green technology is definitely carrying more weight as it is important to consumers and new legislation is coming from government organizations."

Wilkes points to a recent issue of the trade journal *Chemical and Engineering News*, which claims that venture capital funds are also turning to "cleantech" and that green start-ups "will constitute their (venture capitalists) highest growth sector in 2008." Virginia Tech materials engineers and scientists again plan to be in the forefront.

By Lynn A. Nystrom

FACTS AT A GLANCE

A Brief History

The Macromolecules and Interfaces Institute is the convergence of the five internationally known Virginia Tech entities — the Polymer Materials and Interfaces Laboratory, the Center for Adhesion and Sealant Science, and the Center for Composite Materials and Structures — as well as the Materials Research Institute, and the interdisciplinary graduate program in macromolecular science and engineering.

Educational component:

174 Ph.D.s, 137 master's, and 192 bachelor's degrees

Publications:

More than 1,500 technical papers, theses, and dissertations

Approximate Economic Value of the Groups over 40 Years:

More than \$30 million from the NSF; more than \$73 million in research contracts from industry, government, and institutional support

Industrial Affiliates and Fellowship Sponsors (since inception):

Ford Motor Company; 3M; Lord Corp.; The Dow Chemical Co.; Kaneka Texas Corp.; Alteco Korea Inc.; L&L Products; Huntsman Chemical (Vantico Ltd.); Solvay Advanced Polymers LCC; Michelin Americas Research and Development; Michelin Tire Corp.; Reynolds Metals Co.; Sunstar Engineering Inc.; Exxon Chemical Co.; HAP-DONG Chemical Co. Ltd.; Bayer MaterialScience; Eastman Chemical Co.; Omnova Solutions Inc.; Procter and Gamble

Technology Transfer:

53 patents, 6 patents pending, 5 invention disclosures

Outreach to Industry:

92 short courses held, 200 industry internships by materials students

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Tom Dingus, the Newport News Shipbuilding/Tenneco Professor of Civil and Environmental Engineering, directs the Virginia Tech Transportation Institute that attracts \$14 to \$21 million a year in research, allowing it to employ some 250 faculty, staff, and students.

Virginia Tech Transportation Institute

Warning drowsy drivers, identifying urban driver behavior, providing safer school buses — all in a day's work at the university's high-profile research center.

National data collected in 2006 show school bus-related accidents send some 17,000 U.S. children to emergency rooms each year, more than double the number in previous estimates that included just crashes, according to a study reported in the magazine Pediatrics. And a Centers for Disease Control (CDC) 2006

study showed that motor vehicle crashes are the leading cause of death for U.S. teens, accounting for 36 percent of all deaths in this age group.

Increasing school bus safety for children and ways to save lives of novice drivers, especially in sudden-road departure situations, are just two of the many focuses of the Virginia Tech Transportation Institute (VTTI). VTTI is an internationally recognized resource for providing real-time data and analysis to transportation research industry leaders, as well as to legislators for consideration in public policy development on the state and national levels. Virginia Tech's largest university-level research center, VTTI is dedicated to saving lives, money, and time in the transportation field by developing and using state-of-the-art tools, techniques, and technologies to solve transportation challenges.

Started in 1988 as the Center for Transportation Research (CTR) with only a few researchers, it grew to become VTTI in 1999. Over the course of the past 20 years, such developments as a high-level data acquisition system, sophisticated naturalistic driving research methods, the construction of the Virginia Smart Road — as well as the recruitment of an elite team of researchers — has propelled VTTI to the top of the transportation research field.

In 1996, the center was designated as one of the three Federal Highway Administration/Federal Transit Administration Intelligent Transportation Systems (FHWA/FTA ITS) Research Centers for Excellence. In 2005, due to VTTI's continued research leadership, the institute was named the National Surface Transportation Safety Center for Excellence (NSTSCE). NSTSCE is dedicated to using high-tech facilities and equipment, including the Virginia Smart Road, to develop and test transportation devices and techniques that enhance driver performance, examine advanced roadway delineation and lighting systems, and address age-related and driver-fatigue issues. VTTI conducts applied research using a multidisciplinary core of researchers and educates students in the latest transportation technologies through hands-on research and experience.

The Smart Road, owned by the Virginia Department of Transportation (VDOT), is a 2.2-mile, two-lane road, and is the only facility in North America that can provide such a wide array of test environments for transportation research.

Often considered the most high-profile research facility at VTTI, the Smart Road has facilitated 12,500 hours of research since its inception. It features weather-making capabilities, a variable lighting test bed, pavement markings, an on-site data acquisition system (DAS), road weather information systems, differential global positioning system (DGPS), road access and surveillance, and an intersection with signals. The Smart Road, owned by the Virginia Department of Transportation (VDOT), is a 2.2-mile, two-lane road, and is the only facility in North America that can provide such a wide array of test environments for transportation research.

In early 1992, a location for the Smart Road, envisioned as a series of test beds for research and ultimately a highway connection between Blacksburg, and interstate 81, was selected by the Commonwealth Transportation Board. VDOT began designing the road, working closely with FHWA on environmental issues and Virginia Tech's CTR. Then in 1994, Virginia Governor George Allen committed state funding to help build the road. Design of the Smart Road continued, assisted by a Citizens Advisory Committee, and the groundbreaking took place July 8, 1997. The road was completed and opened for research in 2000.

Although the Smart Road has been a valuable research facility for a wide variety of testing, growth in VTTI's naturalistic driving research has contributed to its success. Because of record growth in 2007, vast research opportunities opened up for VTTI. VTTI sought and won the first phase (\$8.2 million) award of an overall project totaling \$20.9 million for Cooperative Intersection Collision Avoidance Systems (CICAS). The long-awaited Strategic Highway Research Program 2 (SHRP 2), directed by the Transportation Research Board (TRB), a division of the National Academies of Sciences, announced VTTI as the prime contractor for the planning phase of the "In-Vehicle Driving Behavior and Crash Risk Study." Winning this project will poise VTTI to be highly competitive for the on-road project with a total dollar award of approximately \$30 million.

VTTI's research complex has also grown over the years and now includes three research buildings totaling more than 50,000 square feet. To supplement and support the focused transportation research of the institute, the facility holds a fully staffed garage and machine shop to instrument experimental vehicles.

Over the years, VTTI has not forgotten its primary goals to increase transportation safety and reliability. The institute hosts over 2,100 people annually at its open house and School Day events, held in cooperation with VDOT. These events allow students and the general public to take a ride on the Smart Road to see the weather-making equipment in action, take a peek inside an instrumented vehicle, watch data stream in with VTTI's specialized system, and watch dispatchers in the Smart Road's control room carefully regulate the day-to-day operation of the Smart Road.

In addition, VTTI has found other ways to help the community. For example VTTI's Center for Truck and Bus Safety and Center for Technology Development teamed with the local police department to increase school bus safety for children in the community. Researchers developed an automated system installed within school buses to reduce illegal passing by cars. The system includes two cameras mounted on the left side of the school bus, one looking forward and one backward, as well as a system box inside. The driver of the bus will have the ability to push an incident button on the system box when an alleged violation has occurred. This will display an additional message on the recorded video, allowing quick video review and location of possible violations later.

And VTTI has addressed teen safety driving issues. In an effort to help save the lives of novice drivers in sudden road-departure situations, Youth of Virginia Speaking Out About Traffic Safety (YOVASO) in conjunction with VTTI, the Virginia State Police, local law enforcement officers, and the division of Motor Vehicles (DMV) filmed a safety video on the Smart Road. This video will be distributed to driver training programs throughout the commonwealth to show teen drivers what happens when a run-off-road situation occurs, how to bring their vehicle safely back onto the main roadway, and how to avoid over-correcting and losing control of their vehicle.

VTTI has received an enormous amount of attention and accolades both nationally and internationally. In 2006, VTTI was recognized worldwide for its groundbreaking study using naturalistic research in the Washington, D.C. area. The 100-Car Naturalistic Driving Study was the first of its kind and has since given way to such research as the 40-Teen Naturalistic Driving Study and the design phase of the SHRP 2 . In-Vehicle Driving Behavior Study.

In addition, VTTI's faculty experts have been widely published in national and international publications including the *New York Times*,

Wall Street Journal, Washington Post, USA Today, and Washington Times.

Tom Dingus, the director of VTTI, is widely recognized for his research in intelligent vehicle highway systems, driver attention demand, driver workload, and other human factors. His research is supported by the Virginia department of Transportation, the National Highway Traffic Safety Administration, the National Academies of Science, National Institute of Child Health and Human Safety, FHWA, General Motors, Ford Motor Company, and many other state and federal agencies and industry groups.

VTTI's research complex has also grown over the years and now includes three research buildings totaling more than 50,000 square feet. To supplement and support the focused transportation research of the institute, the facility holds a fully staffed garage and machine shop to instrument experimental vehicles. "Safety, sustainability, and efficiency in transportation are important to everyone in this country. To improve these vital measures of effective transportation systems we need well-designed research that can be applied to transportation systems, in the near-term and beyond," says Dingus. "We continually strive to refine our research methods with the goal of improving transportation systems in order to save lives, save time, and save money."

By Katie Thacker and Jayme Shepherd

FACTS AT A GLANCE

The Virginia Tech Transportation Institute is the largest university-level research center at Virginia Tech. The institute employs more than 250 faculty, staff, and students working on over 100 projects and is the largest supporter of both undergraduate and graduate students at the university.

VTTI currently houses nine unique centers focusing on virtually all aspects of surface transportation:

- The Center for Automotive Safety Research explores the causes of automobile crashes and ways to prevent them by gathering data from drivers in their everyday environments.
- The Center for Vehicle Infrastructure Safety specializes in safety issues involving vehicle-infrastructure cooperative safety systems, intersection collision avoidance, roadway delineation, and roadway and vehicle lighting.
- The Center for Truck and Bus Safety specializes in safety issue involving heavy truck and bus operations.
- The Center for Sustainable Mobility specializes in sustainable transportation planning with emphasis on mobility, efficiency, environmental, and safety impacts of transportation infrastructure.
- The Center for Sustainable Transportation Infrastructure specializes in improving pavement and infrastructure technologies and practices and in conducting high-impact research for accelerating the renewal, increasing safety, reducing life-cycle costs, and ensuring sustainability of transportation infrastructure systems.
- The Center for Technology Development develops, manufactures, implements, and maintains innovative data acquisition, collection, logistics, and analysis systems in support of transportation research.
- The Center for Product Development was created to further refine raw transportation research technologies to viable commercial technologies. The center's staff packages these refined technologies as transportation safety products for the commercial market.
- The Center for Injury Biomechanics (CIB) is an interdisciplinary research center that combines the talents of the Virginia Tech College of Engineering with the Wake Forest University School of Medicine along with a partnership with VTTI. CIB performs research investigating human tolerance to impact loading. The application of this research includes automobile safety, military restraints, and sports biomechanics.

Research:

Some 114 companies and government agencies have partnered or sponsored research work with VTTI.

Annual Research Expenditures:

Approximately \$14-\$21 million

Publications:

Many of VTTI's hundreds of reports can be located by searching TRIS — Transportation Research Information Service Online. Searching can be done by keyword, author, title, subject, or transportation research thesaurus terms. Reports from projects funded by the federal government can be found by searching all of the U.S. Department of Transportation websites or by visiting the sponsoring agency's website (e.g., Federal Highway Administration, National Highway Traffic Safety Administration, Federal Motor Carrier Safety Association). NOTE: Including "VTTI" as a search term along with an author or keyword will streamline search results.

For a tour, go to www.vtti.vt.edu/tour.html.



Examples of Significant Impact Studies:

100-Car Naturalistic Driving Study

This study, funded by the National Highway Traffic Safety Administration, the Virginia Transportation Research Council, and the Virginia Department of Transportation, sought to investigate naturalistic driving behavior in an urban environment. Researchers instrumented 80 privately owned vehicles and 20 leased vehicles with a data collection system consisting of five cameras and a sensor suite that gathered continuous data for approximately 12 months.

Drowsy Driver Warning System Field Operational Test (DDWS FOT)

A Drowsy Driver Warning System (DDWS) detects physiological and/or performance indications of driver drowsiness and provides feedback to drivers regarding their states of drowsiness. The primary goal of this FOT was to determine the safety benefits and operational capabilities, limitations, and characteristics of the DDWS. Over 12 terabytes of data were collected in this study, making this the largest on-road data collection effort ever conducted by the U.S. DOT.

Safety and Productivity Impacts of New Hours-of- Service Rules

VTTI and subcontractor Hendrix Consulting conducted a one-year project for the American Transportation Research Institute to analyze the safety and productivity impacts of the new commercial driver hours-of-service (HOS) rules, which became effective on Jan. 4, 2004.

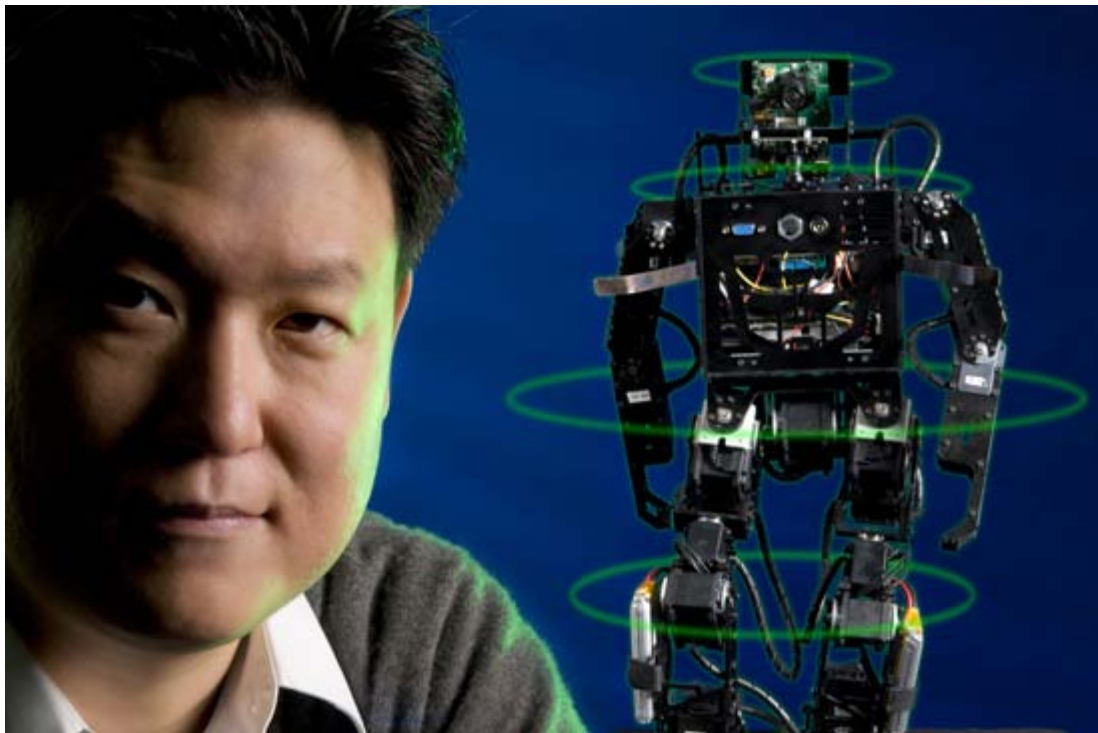
40-Teen Study

Sponsored by the National Institutes of Child Health and Human Safety, this is an 18-month study to better understand the issues associated with newly licensed teen drivers who are at a much higher crash risk when compared to other drivers.

Older Driver Naturalistic Observation Study

This study is a one-year study to better understand older drivers (75+), who are at a much higher crash and fatality risk per mile driven compared with younger drivers. It examines how older adults drive, their impairment profiles, and what situations are the riskiest for this group.

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Dennis Hong, a National Science Foundation CAREER Award recipient, directs RoMeLa, the Robotics and Mechanisms Laboratory at Virginia Tech. Participating students design prototypes that may become some of the world's most advanced and useful robots. Among their creations is DARwin (Dynamic Anthropomorphic Robot with Intelligence), the only U.S. entry invited to participate in the Humanoid League at the international RoboCup 2007.

Virginia Tech Center for Autonomous Vehicles Systems

Students' ingenuity is world renowned for designs of ground to aerial robotics.

If the engineering students at Virginia Tech are a litmus test for the success of autonomous systems research, this emerging strength in the Virginia Center for Autonomous Systems (VaCAS) at the university illustrates its national leadership in this crucial 21st century technology. VaCAS faculty members advise student teams and perform basic research in vehicle autonomy.

Examples of student success abound. In fall 2007, a team of Virginia Tech engineering and geography students won third place and \$500,000 in the Defense Advanced Research Projects Agency (DARPA) Urban Challenge. Tony Tether, director of DARPA, was particularly complimentary of the Virginia Tech entry, according to Charles Reinholtz, one of the engineering faculty advisors for the project.

And whereas it was reported that second place winner Carnegie Mellon spent some \$5 to \$6 million on its driverless vehicle, and that the first place entry from Stanford was also in this heavily financed realm, Virginia Tech's team accomplished almost the same results and spent only \$1 million. The team did have support from engineering alumni of its robotics program who formed a company called TORC Technologies LLC, located at the university's Corporate Research Center. VaCAS members Al Wicks and Dennis Hong, faculty in the mechanical engineering department, also served as advisors in addition to Reinholtz.

This 2007 effort followed a strong showing in the 2005 DARPA competition. In 2005, a Virginia Tech team comprising only undergraduate and graduate students built and fielded two entries, "Cliff" and "Rocky." These vehicles outperformed all other vehicles that were developed without significant corporate involvement. Fielding two entries in the competition was an extraordinary accomplishment — only 40 of the original 195 entries from around the nation (including many entries from private industry) survived the first phase of competition.

The success of Virginia Tech's student design teams in autonomous vehicle research is attributable, in part, to the breadth and depth of faculty expertise in unmanned systems. During the past decade, the interdisciplinary cooperation of faculty with interest in this topic led to the formation of VaCAS, with six core faculty and some two dozen affiliates representing 11 departments in three colleges.

In a different international autonomous event, the Intelligent Ground Vehicles Competition, Virginia Tech has a strong tradition of dominating the awards, placing first in 2007, 2006, and 2005. In 2004, the team placed best overall and won six of nine categories, and was the only group from the U.S. to place in any category. The team also won the competition in 2000 and in 1998. Visit www.igvc.org/results.htm for all team results in this cutting-edge, multidisciplinary competition that encompasses the latest technologies of autonomous systems. Displaying their talents in yet another worldwide contest, the Virginia Tech Aerial Robotics Team entered the International Aerial Robotics Competition. In 2006, its initial year as a contestant, the team won first place overall honors for its

computer-controlled Bergen helicopter. And Virginia Tech was the only U.S. university to have a student team compete in the 2007 RoboCup Humanoid Division Soccer Tournament in Atlanta, Ga. Hong, a robotics expert, also advised this team.

Virginia Tech students have accepted the challenge of developing not only autonomous ground and air vehicles, but also autonomous underwater vehicles (AUVs). Virginia Tech's AUV team participates in an annual engineering design competition aimed at expanding the ability of AUVs to sense and make decisions in unknown or changing environments. This team is co-advised by VaCAS members Dan Stilwell, an associate professor of electrical and computer engineering, and Craig Woolsey, an associate professor of aerospace and ocean engineering.

The success of Virginia Tech's student design teams in autonomous vehicle research is attributable, in part, to the breadth and depth of faculty expertise in unmanned systems. During the past decade, the interdisciplinary cooperation of faculty with interest in this topic led to the formation of VaCAS, with six core faculty and some two dozen affiliates representing 11 departments in three colleges. Woolsey currently serves as the inaugural director of VaCAS.



VaCAS was formally established in fall 2006, with financial support from Virginia Tech's Institute for Critical Technology and Applied Science. The center facilitates interdisciplinary research in autonomous systems technology, hosting research activities that span every application domain: water, land, air, and space.

Both Woolsey and Stilwell are recipients of prestigious NSF Faculty Early Career Development Program (CAREER) Awards, as well as the Office of Naval Research (ONR) Young Investigator Program Award to support and enhance their early research efforts. Hong has also

received the NSF CAREER Award.

Woolsey's CAREER and ONR awards provided him with initial funding to study the design of advanced controls and control mechanisms for unmanned vehicles. Woolsey is developing nonlinear control theory to improve the maneuverability, robustness, and reliability of underwater, air, and space vehicles. One application of immediate interest to the Navy involves the use of a streamlined underwater vehicle to survey underwater mine fields.

Stilwell used his CAREER and ONR awards to develop a fleet of miniature underwater vehicles that enable scientists to gather environmental data in areas such as the coast of Virginia, the Chesapeake Bay, and the Gulf of Mexico. Stilwell's objectives include the development of a low-cost miniature AUV, development of a mathematical theory to describe how AUVs can cooperate, and deployment of a fleet of vehicles to gather environmental data that would otherwise be impossible to collect.

Using his CAREER award, Hong is designing a Whole Skin Locomotion (WSL) mechanism to work on much the same principle as the pseudopod — or cytoplasmic "foot" — of the amoeba. With its elongated cylindrical shape and expanding and contracting actuator rings, the WSL can turn itself inside out in a single continuous motion, mimicking the motion of the cytoplasmic tube that an amoeba uses for propulsion.

"Our preliminary experiments show that a robot using the WSL mechanism can easily squeeze between obstacles or under a collapsed ceiling," Hong says. "This unique mobility makes WSL the ideal locomotion method for search-and-rescue robots that need to travel over or under rubble. The mechanism also has the potential for use in medical applications — such as robotic endoscopes, for example, where a robot must maneuver in tight spaces."

Woolsey also directs the Nonlinear Systems Laboratory (NSL), a facility for research and instruction in control of nonlinear systems. The NSL's primary emphasis is autonomous vehicles. Woolsey and his colleagues have developed a fleet of unmanned aerial vehicles (UAVs) to demonstrate such applications as vision-based flight control and flight vehicle coordination. One of these UAVs was used, together with an unmanned surface vehicle developed by Stilwell and the "Rocky" vehicle from the DARPA Grand Challenge, to successfully demonstrate autonomous riverine reconnaissance operations at the ONR-sponsored AUVFest in Panama City, Fla., in 2007. This effort was a close collaboration with colleagues at the Naval Postgraduate School in Monterey, Calif.

VaCAS was formally established in fall 2006, with financial support from Virginia Tech's Institute for Critical Technology and Applied Science. The center capitalizes on more than a decade of work in various aspects of autonomous systems research, work that began under Reinholtz, an award-winning professor of ME who has since assumed an administrative post at a Florida university. The center facilitates interdisciplinary research in autonomous systems technology, hosting research activities that span every application domain: water, land, air, and space. VaCAS member research activities range from fundamental control theory to vehicle development to applications for science, security, and commerce.

Areas of research that have the most potential to impact the future of autonomous vehicle systems include advanced guidance, navigation, and control; advanced structures and materials; human/computer interaction; wireless communication; aerodynamic and hydrodynamic modeling; multidisciplinary design optimization; power systems; alternative fuels; and optimal power management. Virginia Tech faculty, members of VaCAS or otherwise, have demonstrated excellence in each of these critical areas to help position Virginia Tech as an international leader in autonomous systems research and development.

By Lynn Nystrom

FACTS AT A GLANCE

A Brief History

In October 2006, the Virginia Center for Autonomous Systems was established as a research center of the Virginia Tech Institute for Critical Technology and Applied Science. The center's primary purpose is to advocate and support a broad range of basic and applied interdisciplinary research activities focused on autonomous system technology. The center's web address is www.unmanned.vt.edu.

Research Team

6 core faculty from 3 departments
25 affiliated faculty from 10 departments in 3 colleges

Educational Component:

During the 2006-07 academic year, VaCAS core faculty advised 29 Ph.D. students and 28 master's students.

Publications

During the 2006-07 academic year, VaCAS core faculty published 22 peer-reviewed journal articles with 20 more in review (at the year's end) as well as 91 conference papers with nine more in review.

Economic Value of the Group:

During the 2006-07 academic year, VaCAS core faculty submitted 38 proposals with requests totaling nearly \$27 million. Thirteen proposals were funded, totaling just over \$5 million.

Industrial Affiliates:

VaCAS initiated an industry affiliates program in September 2007 with a kickoff meeting at the Inn at Virginia Tech. The meeting featured "dinner & demos" at nearby Claytor Lake State Park. Consultations are still underway with several prospective affiliates.

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Wayne Scales, director of the Center for Space Science and Engineering Research at Virginia Tech (Space@VT), successfully attracted National Science Foundation funding to create the center and helped persuade the highly successful SuperDARN Radar Group to relocate to Virginia Tech.

Space@VT

An emotional tie, and three strikes of lightning later brings success.

The naysayers said it couldn't be done. But sheer determination on the part of Wayne Scales proved them wrong.

In 1992 Scales was among the nation's entry-level assistant professors of electrical engineering. His specialty — space plasma physics — was not the topic of a household dinner conversation. Only a handful of universities in the country were powerhouses in space research. They included Cornell, where he obtained his Ph.D., Stanford, University of Washington, University of Michigan, and several schools in the University of California system, including Berkeley.

Cornell, the home of the late Carl Sagan, encouraged Scales to consider joining its faculty. When he countered that he planned to join the Virginia Tech Bradley Department of Electrical and Computer Engineering (ECE), they were surprised. Since Virginia Tech did not have a space science and engineering program, his Cornell colleagues felt Scales would not be satisfied in Blacksburg and that it would be too difficult for him to initiate an enormously expensive competitive research program by himself.

But Scales had an emotional tie to Southwest Virginia that outweighed the interest of other universities and government laboratories. He was the only child in his family, and he wanted to live near to his mother, who still resided in Ridgeway, Va., following his father's recent death. Scales followed his heart. His intellect and his fortitude prevailed, opening a number of doors, and in a little more than a decade, he became the director of the Center for Space Science and Engineering Research at Virginia Tech (Space@VT) with annual research revenues of about \$2.5 million. Space@VT is now making its own headlines around the world.

The center was the result of a successful proposal that Scales and Joseph Wang of aerospace and ocean engineering (AOE) submitted to the National Science Foundation (NSF). It awarded them \$805,000 in 2005 to create the interdisciplinary center for space research. Scales became the director and Wang the associate director. The NSF funding allowed the hiring of Brent Iedvina, one of the most highly respected young space scientists nationally. Next came Scott Bailey, a talented young space instrument and space mission scientist from the University of Alaska, Fairbanks, which has one of most highly recognized space science programs in the world. last, but certainly not

least, came Robert Clauer, one of the most noted names in magnetospheric physics in the country and a former NSF program manager, as the third member of the initial Space@VT cluster hire. Clauer was designated as the second associate director.

"These were like three strikes of lightning," Scales reflects, "and the next bolt came" shortly afterward. Within a year of the research center's announcement, Virginia Tech was able to persuade the highly prestigious SuperDARN Radar Group to relocate from Johns Hopkins University's Applied Physics Laboratory (JHU APL) to the Blacksburg campus.

In enticing the group to come to Blacksburg, Scales and his colleagues capitalized on Virginia Tech's advantage of having the ability to award Ph.D.s (APL's research centers cannot) and utilization of the initial NSF support to create a doctoral specialization in space science in ECE and AOE, including the development of several new space-oriented courses: introduction to Space Weather, Magnetospheric and Ionospheric Physics, and Environmental Radar Techniques.

This commitment to graduate education and the possibility of tenure-track faculty positions provided the necessary incentive to the API group to relocate to Virginia Tech. At APL, the group was receiving more than \$1 million annually from NSF — a government agency that looks at Ph.D. production as one of its primary missions. Scales says this primary criterion enabled him and others, including ECE department Head James Thorp and engineering dean Richard Benson, to convince the APL researchers to relocate to Blacksburg. "This group is rated the number one space science experimental facility in the upper atmosphere division," he adds.

The SuperDARN network is an international radar network for studying the Earth's magnetosphere, ionosphere, and connection into space. The APL group is now operating its radar at Virginia Tech's Blackstone Agricultural Research and Extension Center. New faculty members Joseph Baker and Michael Ruohoniemi are responsible for its daily operations, aimed at studying magnetic storm associated electric fields. Ray Greenwald, described by Scales as the "godfather" of the SuperDARN group, is now retired but continues to consult with them.

"It makes sense that Virginia should excel in space science and engineering. We are close to Washington, D.C., which has numerous private firms and government agencies interested in space technology. Also, Wallops Island, Va., is expected to become a more prominent launch facility. We have the Virginia Space Grant Consortium and the National Institute of Aerospace" (NIA) located in Hampton, Va. "A lot of things are coming into alignment," Scales says.

With the advantage of being able to award Ph.D.s, Virginia Tech was able to attract the SuperDARN Radar Group to Virginia. SuperDARN consists of chains of radar distributed in both hemispheres for research purposes.

Clauer's office is physically located at the NIA, a consortium of universities established in 2002 to develop excellence in research and education in a spectrum of aerospace related areas of study, including space science. Other member universities include Georgia Tech, University of Maryland, University of Virginia, North Carolina State, Hampton University, and North Carolina A&T State. This consortium teams with the NASA Langley Research Center in Hampton to conduct some of the nation's most advanced aerospace and atmospheric research.

But Virginia is just one piece of the equation for Space@VT. For example, Clauer is working to establish an Antarctic chain of autonomous magnetic observatories along the 400 magnetic meridian. A prototype system has been tested successfully at the South Pole during the past two years. "The Sun-Earth system is our laboratory," Clauer says. "It is a large electrodynamic system and the space weather in this system can affect many important technologies upon which our society depends." Space weather includes galactic cosmic rays, micrometeoroids, solar cell damage, plasma bubbles, airline passenger radiation, and more.

Space weather phenomenon adversely affects spacecraft, satellites, and astronauts as well as communication, navigation, and power systems on Earth. Space@VT research therefore supports various spacecraft engineering and technology development projects. The aurora borealis is one of the most visible manifestations of space weather.

Scott Bailey, a new assistant professor of ECE, is working at the opposite end of the Earth, along with Chris Hall of AOE, to launch a sounding rocket from Poker Flat, Alaska, in 2010. The sounding rocket experiment will demonstrate if stellar occultation is a viable technique to measure nitric oxide (NO). According to Bailey, "there is growing evidence showing that solar energetic particles lead to the production of ozone-destroying nitrous oxide (NO)." The project is being conducted with Colorado University's Laboratory for Atmospheric and Space Physics.

"Scott is one of the youngest people in the country to be competing at the level he is at," Scales asserts.

Scales also credits the Space@VT Advisory Board for much of the group's progress. Dan Sable, president of VPT Inc., serves as the chair of the board. "Dan has been critical to our success with his knowledge of businesses and space research," Scales says. VPT Inc. designs and manufactures electronic power converters used in satellite applications and is also a member of the Virginia Tech Center for Power Electronic Systems industry-university affiliate program. According to Sable, "Such programs provide support for education and research and help advance the industry by transferring information through the employment of students who are not only skilled, but attuned to an industry segment's interests and needs. As a side benefit, it trains future electrical, computer, and aerospace engineers in the use of VPT products for space applications."

Other members of the Advisory Board include representatives from Boeing, Orbital Sciences Corp., Northrop Grumman, Lockheed Martin, BAE Systems, and several other industries and government agencies.

"Support for our group is very broad, and most importantly, we are well-rooted in science. All of the engineering work will follow," Scales says. Current research focuses on a wide range of topics, including upper atmospheric science, sun-Earth connections, space instrument design, space mission design, remote sensing, magnetospheric and ionospheric physics, ground-based instrument design, ground-based space weather studies, Global Navigation Satellite System GNSS receivers and space weather applications, computational space plasma physics, active space experiments, spacecraft dynamics and control, spacecraft design, spacecraft environmental interactions, and advanced space propulsion systems.

Space@VT is also making a concentrated effort to engage underrepresented groups in science and engineering in general, and in space science and engineering in particular. It is developing joint research and educational ventures with minority serving institutions (MSIs),

such as the Inter-American University in Puerto Rico and North Carolina A&T. Puerto Rico has the Arecibo Observatory, "a world-famous facility," Scales says, and so it makes sense to be working with this primarily Hispanic island. "These MSIs, primarily undergraduate in nature, provide a pipeline for students to enter our graduate program.

"Within the next year, Scales hopes two more current Virginia Tech faculty members will consider joining Space@VT, including a radio astronomer and a former director of space science at the Naval Research Laboratory.

By Lynn A. Nystrom

FACTS AT A GLANCE

A Brief History

The Center for Space Science and Engineering Research at Virginia Tech (Space@VT) was officially founded in the summer of 2007 as part of Virginia Tech's College of Engineering. An interdisciplinary center, Space@VT's faculty members have international reputations in the fields of space science and engineering and currently hold academic appointments in the Bradley Department of Electrical and Computer Engineering or the Aerospace and Ocean Engineering Department.

Research team:

Wayne Scales, professor of ECE, director
Robert Clauer, professor of ECE, associate director
Joseph Wang, associate professor of AOE, associate director

Scott Bailey, assistant professor of ECE
Christopher Hall, professor of AOE
Brent Ledvina, assistant professor of ECE
Daniel Weimer, research professor of ECE
Joseph Baker, assistant professor of ECE
Michael Ruohoniemi, associate professor of ECE
Ray Greenwald, research professor of ECE

Industrial Affiliates:

The advisory board provides input on research opportunities and direction, as well as guidance for curricula and training for educating future space science and engineering students. Members of the Space@VT advisory board are leaders in the fields of space science, space engineering, and space technology. The current membership is: Dan Sable, VPT Incorporated, chairman; Richard T. Cervisi, the Boeing Company; Robert Erlandson, the Johns Hopkins Applied Physics Laboratory; Robert Fulton, Orbital Sciences Corporation; Peter Hadinger, Northrop Grumman Corporation; Michael Hurley, Naval Research Laboratory; Michael Keeton, Orbital Science Corporation; John Logrando, Lockheed Martin Corporation; Gino Manzo, BAE Systems; Craig Purdy, NASA Goddard Space Flight Center; Patricia Remias, Aeroastro Incorporated; Lew Roufberg, the Johns Hopkins Applied Physics Laboratory; Joseph Suter, the Johns Hopkins Applied Physics Laboratory; Dennis Sweeney, the Aerospace Corporation; Timothy Winter, Northrop Grumman Corporation; and Brandon Witcher, Sandia National Laboratories.

Ph.D. students advised: 18

M.S. students advised: 10

Journal papers published: 38

Conference papers published: 25

Articles in review: 16

Proposals submitted: 32

Funding requested: \$112,151,000

Proposals funded: 25

Funding acquired: \$4,661,000

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Wu Feng is oftentimes referred to as "The Green Destiny Guy" in the scientific community. Green Destiny debuted in early 2002 as a major accomplishment of the Supercomputing in Small Spaces project. A 240-processor supercomputer with a footprint of five square feet and a power envelope of a mere 3.2 kilowatts, Green Destiny produced an admirable Linpack rating of 101 Gflops, operated without any unscheduled downtime for its two-year lifetime while running in an 85° F warehouse at 7,400 feet above sea level with no air conditioning, no air humidification, and no air filtration. Green Destiny garnered international attention in more than 100 media outlets including BBC News, CNN, and The New York Times and led, in part, to Feng being named to HPCwire's Top People to Watch List in 2004. He has since been instrumental in the development of the Green500 List, a ranking of the most energy-efficient supercomputers in the world.

High-End Computing

The "third pillar" of scientific discovery starts here.

In 2003, the System X supercomputer put Virginia Tech on the technical map with respect to high-end computing (HEC), and the timely investment in HEC faculty during this decade has helped move Virginia Tech toward the upper echelons of research prominence.

With computing, and particularly HEC, taking its place as the "third pillar" of scientific discovery among the traditional pillars of theory and experimentation, the demand for computational cycles continues to grow at an astonishing rate. For example, many areas of computation science study the universe via first-principles analysis, thus enabling the observation of systems that are too small, too large, or too dangerous for direct experimental observation.

Virginia Tech's investment has led to the creation of its Center for High-End Computing Systems (CHECS). CHECS members investigate a broad array of problems and design a wide range of technologies — all with the goal of developing the next generation of powerful and usable high-end computing resources. It was established in September 2005 and is supported by Virginia Tech's College of Engineering.

CHECS has brought in more than \$2 million of funding with more than \$4 million pending. Two of the more recent and notable grants include a \$400,000 National Science Foundation (NSF) Faculty Early Career development award for Ali R. Butt of computer science (CS), as well as a \$300,000 NSF Computer Systems Research grant to Godmar Back and Dimitrios Nikolopoulos, also of the CS department, in the area of high-performance virtual computing for both capability and capacity supercomputing.

"We have gotten off to a promising start in HEC at Virginia Tech. System X, which was designed and architected by Srinidhi Varadarajan of CS, started the ball rolling in terms of visibility and impact in HEC in 2003. The investment in lines of faculty hire by the College of Engineering has further strengthened this emerging area for Virginia Tech.

In addition, CHECS has garnered international recognition, including three IBM Faculty Awards that were secured by CS faculty members Wu Feng, Kirk Cameron, and Dimitris Nikolopoulos, as well as a Best Paper Award, "Dynamic Multigrain Parallelization on the Cell Broadband Engine" by Filip Blagojevic, Dimitris Nikolopoulos, Alexandros Stamatakis, and Christos D. Antonopoulos. Their paper

enables biologists to more efficiently construct the Tree of life and accelerate phylogenetic analysis, which is used extensively in medical research for such endeavors as the understanding of the spread of various viruses, including HIV.

HEC at Virginia Tech has also made tremendous impact as a third pillar of scientific discovery, ranging from materials science and engineering through Professor Diana Farkas' research in atomistic computer simulation of alloys, to computer and computational science through Feng's research on an innovative distributed computing framework called ParaMEDIC, which recently supported an effort to find missing genes in genomes.

ParaMEDIC stands for "Parallel Metadata Environment for distributed I/O and Computation." I/O refers to the input/output of a storage system. Pavan Balaji of Argonne National Lab and Feng created this scalable framework in order to tackle the sequence searching of all the known microbial genomes against each other. Their purpose was to enable the discovery of missing genes in genomes and generate a complete genome similarity tree. The tree is based on the results of sequence-searching the microbial genomes and would be used to speed up future sequence searches.

"This computation could not be solved with the HEC compute, network, and storage resources of any single supercomputing site. We had to aggregate over 12,000 processors, distributed across six supercomputing centers in the U.S., as well as efficiently utilize the distributed cyberinfrastructure that connected these computational resources in order to handle the expected petabyte of output that would then need to be shipped over a shared trans-Pacific gigabit Ethernet network link to a 0.5-petabyte filesystem in Japan," Feng explained.

The development of ParaMEDIC allowed missing genes in genomes to be discovered, and a complete genome similarity tree was generated. The software allowed what could have been a three-year project to be completed in less than two weeks.

If standard HEC tools had been used over a shared gigabit Ethernet connection, it would have taken on the order of three years to transfer the information. The distributed cyberinfrastructure was available to Feng and Balaji only for a two-week period. Consequently, they developed ParaMEDIC and reduced the three-year run time down to less than two weeks.

Feng was also instrumental in developing the Green500 list, a ranking of the most energy-efficient supercomputers in the world. His hope is the list will shift the focus of supercomputing design to the adoption of a more energy-efficient approach.

The notion of a Green500 list actually dates back to April 2005 during a keynote talk that Feng gave at the IEEE IPDPS Workshop on High-Performance, Power-Aware Computing. Formalizing the need for a Green500 list came a year later with a paper and associated talk entitled "Making a Case for a Green500 list."

A subsequent presentation at Clusters and Computational Grids for Scientific Computing 2006, entitled "Global Climate Warming? Yes ... in The Machine Room," led to more fervent interest, and ultimately, the announcement of the Green500 at Supercomputing 2006. One year later at Supercomputing 2007, the inaugural list was released and has arguably started a new era in green supercomputing.



Since its debut in 2004, System X has served Virginia Tech well. Researchers have used the supercomputer to track pathways in the protein myoglobin, to explore the biochemical landscape to find memory switches that support important biological functions, and many more previously unanswered scientific and technological questions.

FACTS AT A GLANCE

"We have gotten off to a promising start in HEC at Virginia Tech. System X, which was designed and architected by Srinidhi Varadarajan of CS, started the ball rolling in terms of visibility and impact in HEC in 2003. The investment in lines of faculty hire by the College of

Engineering has further strengthened this emerging area for Virginia Tech.

"However, substantive and recurring investments are needed in order to help propel Virginia Tech into international prominence. Specifically, we need to be taken seriously as a key player in HEC with respect to research, production, and service. Institutions such as Louisiana State University, Georgia Tech, University of North Carolina, University of Illinois at Urbana-Champaign, University of Tennessee, and University of Texas already enjoy their respective states' recognition of HEC as the third pillar of scientific discovery, and they are making substantial investments for long-term economic growth and research prominence in HEC," Feng says.

Compiled by Christina Daniilidi

Research Team

Godmar Back
Ali Butt
Kirk Cameron
Wu Feng
Dennis Kafura
Dimitris Nikolopoulos
Cal Ribbens
Adrian Sandu
Eli Tilevich
Srinidhi Varadarajan
Layne Watson

Publications

2005: 22
2006: 36
2007: 61

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Rafael Davalos is one of two inventors of a new technology, irreversible electroporation, that uses electric pulses to destroy cancer tissue. Named by NASA Tech Briefs as one of seven key technological breakthroughs of 2007, Davalos is receiving additional support aimed at moving the procedure to the marketplace — an Early Career Translational Research Award in Biomedical Engineering from the Wallace H. Coulter Foundation. Davalos is a faculty member of the Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences, part of the Institute for Critical Technology and Applied Science.

Institute for Critical Technology and Applied Science

ICTAS creates technological research without boundaries, leading to a host of impressive achievements.

The February 2008 issue of Analytical and Bioanalytical Chemistry featured the groundbreaking work of Rafael Davalos and his team of researchers on its cover for their research into the application of specific types of polymer devices. Just a few months earlier, Davalos, a member of the Virginia Tech-Wake Forest School of Biomedical Engineering and Sciences (SBES), received notification from NASA Tech Briefs that another aspect of his work, done in conjunction with Boris Rubinsky of the University of California at Berkeley, on targeting cancer cells with electric pulses was one of the seven top technological breakthroughs of 2007. SBES is part of Virginia Tech's Institute of Critical Technology and Applied Science (ICTAS).

At the International Supercomputing Conference 2007, top researchers in high-performance computing, Wu-Chun Feng of the computer science department at Virginia Tech, and ICTAS doctoral scholar Jeremy Archuleta were among the recipients of the Storage Challenge Award. The award cites them for developing the most effective approach in using large-scale storage for high-performance computing. They teamed with Argonne National Laboratory and North Carolina State University on this work.

When the National Science Foundation wanted expert opinion on the important questions that need to be addressed in order to advance the understanding of nanoparticles in the environment, it contacted ICTAS' technology focus area leader, Michael Hochella Jr., to assemble a group of cutting-edge young scientists with new ideas. "While we were together, we thought, why not write our study and submit it to Science," Hochella says. So, he put together a team of scientists from seven universities as authors of a review article that appeared in the March 21, 2008, issue, called "Nanominerals, Mineral Nanoparticles, and Earth Chemistry." Hochella, a University Distinguished Professor of geosciences at Virginia Tech, is a pioneer in the emerging field of nano-bio-geochemistry, which is believed to be a critical part of studies of the global environment. He was the first in his field to use atomic-force, scanning-tunneling microscopes, and high-resolution transmission electron microscopes to study surface properties at the atomic level.

These representative successes under the umbrella of ICTAS, garnered in just a few months time, are indicative of this collaborative work environment's penchant for impressive achievements. ICTAS director Roop Mahajan, the recipient of the 2007 Ralph Coats Roe Medal for his contributions to a better understanding and appreciation of the engineer's value to contemporary society, is himself an internationally known prolific researcher with expertise in a number of fields, including heat transfer, artificial neural networks, bio-micro-electro-mechanical systems (Bio-MEMS) and nanotechnology.

Mahajan was appointed ICTAS' first permanent director in 2006, following several years of concept development based on a vision presented in 1998 by Malcolm McPherson. Now a retired associate dean of research and graduate studies of the College of Engineering, McPherson argued some 10 years ago that without significant investment, the College of Engineering was more likely to remain at status quo or decline in the rankings.

So, McPherson looked at models at other universities, including the Georgia Tech Research Institute, Lawrence Berkeley Labs (University of California at Berkeley), and Texas A&M's Engineering Experiment Station. Each of these institutes had several key features: significant initial investment, ongoing state support, a high degree of economic development, research space in shared facilities, and a strong collaboration among the faculty in the sciences and engineering. McPherson understood that a research institute would not work for engineering unless there was a collaborative model that involved partnership with other colleges at Virginia Tech.

Today, under Mahajan's leadership, ICTAS is fulfilling McPherson's vision. It is a strong and vibrant research environment that has enabled the College of Engineering to better partner with superb researchers in other colleges at Virginia Tech. Mahajan immediately began working with the leading researchers throughout the university to establish Virginia Tech's view of how it could best invest its resources in a few selected areas that would result in pre-eminent national and international status. The result — all of ICTAS' focus and theme areas are either subsets of or at the intersection of these major four areas of technology: nanotechnology, cellular and molecular biology, information technology, and cognitive systems, and with a bias for sustainable development. The focus areas include nanoscale science and engineering, nano-bio interface, sustainable energy, renewable materials, water and cognitive systems, and communications.

ICTAS' nanoscale science and engineering focus area is led by Hochella and includes faculty from chemistry, civil and environmental engineering (CEE), geosciences, and physics.

All of ICTAS' focus and theme areas are either subsets of or at the intersection of these major four areas of technology: nanotechnology, cellular and molecular biology, information technology, and cognitive systems, and with a bias for sustainable development.

At the nano-bio interface, a major thrust is the field of targeted delivery of nano-medicine. Researchers from chemical engineering, biomedical science and pathobiology, physics, biomedical sciences, electrical and computer engineering (ECE), chemistry, wood science and forest products (WSFP), and the large animal clinical sciences are working together to meet technology challenges.

Mike Ellis of mechanical engineering (ME) leads the sustainable energy efforts and is joined by faculty from seven different departments in the colleges of Agriculture and Life Sciences, Engineering, and Science.

Back in the early 1990s, when Wayne Clough was dean of the College of Engineering, he identified green engineering as a focal point, placing the college on the national radar screen as a pioneer in this effort. A few years ago, Sean McGinnis of materials science and engineering (MSE) was hired to facilitate the college's efforts, and now his job has expanded to ICTAS. The ICTAS renewable materials group includes members of the departments of biological systems engineering (BSE), MSE, and WSFP.

Under the leadership of John Novak, the water focus area will have three concentrations: urban watersheds, groundwater/surface water interface, and water and wastewater infrastructure sustainability. In the first area, Tom Grizzard of CEE provides ICTAS with a strong background in urban watersheds. He served as the director of the Occoquan Watershed Monitoring laboratory in Manassas, Va., for 29

years. He conducted long-term research and analysis of the water quality and watershed management issues associated with using reclaimed water to enhance the drinking water yield from the Occoquan Reservoir, a large impoundment that is a key part of the water supply for more than 1 million northern Virginians.

Grizzard's new challenges through the ICTAS association will be to build on his vast experience to focus on water reuse, the link between land use and water quality, and the urban water use challenge. His collaborators will come from the departments of biology, forestry, BSE, urban affairs and planning, and CEE.

The groundwater/surface water interface will involve faculty from CEE, BSE, geology, as well as from the Colorado School of Mines.

In the area of water and wastewater infrastructure sustainability, noted MacArthur Fellow recipient Marc Edwards of CEE, along with John Novak, the editor of the Journal of Residuals Science and Technology, and NSF Young investigator and CAREER award winners Bill Knocke and Peter Vikesland, respectively, will be among the collaborators. Faculty from biology, urban affairs and planning, and MSE will join this team.

The cognitive systems and communication area includes human-computer interactions, spatial cognition, immersive virtual environment, cognitive radio networks, and advance computing. A successful "research infrastructure" award from NSF in the mid-1990s allowed the construction of specialized laboratories for HCI research. In advanced or high-end computing, faculty from the computer science department and members of the information technology group on campus led the effort to build SystemX, a 10+ teraflop, 2200-processor cluster which made its debut in fall 2003 as the third most powerful supercomputer in the world. Computer science faculty also lead the Center for High-End Computing Systems and several research labs, including the laboratory for Advanced Scientific Computing and Applications and the Scalable Performance laboratory.

In addition to investments in these areas, ICTAS is supporting other ongoing initiatives, such as the Virginia Center for Autonomous Systems, Wireless @ Virginia Tech, Virginia Tech Transportation Institute, Center for Innovation in Construction Safety and Health, Materials Center of Excellence, and the Next Navy Composites.

ICTAS' performance will allow it to be "seen as a key player for economic development" in Virginia. The College of Engineering attributes the success of ICTAS to its entrepreneurial nature.

Mahajan believes the high-quality, stellar research that is evolving from the ongoing interdisciplinary work will result in some \$50 million in research expenditures by 2011. ICTAS' performance will allow it to be "seen as a key player for the economic development" in Virginia, and part of the strategy is a "high-risk, high pay-off," he adds.

The Commonwealth Research Initiative provided almost \$5.4 million in support of the \$10 million in research equipment installed in the first ICTAS building, the Nanoscale Characterization and Fabrication laboratory (NCFL). The NCFL was created to provide researchers with tools to work in converging disciplines at nano dimensions. It opened in the fall of 2007 and provides convenient access to expensive equipment, allowing investigation of novel phenomena and technology transformation that responds to critical challenges.

ICTAS I, a four-story building on the engineering side of campus, will open in the 2008-09 academic year, housing ICTAS headquarters, SBES, additional nanotechnology research, fuel cells, and renewable materials. ICTAS II, planned for construction in the life Sciences Corridor on campus, is currently under design and will provide another 77,000 square feet.

The ICTAS doctoral Scholars Program was established in 2007, honoring 11 exceptional Ph.D. applicants through the award of full financial support. The program is jointly sponsored by departments, colleges, and the Graduate School. The goal is to establish a steady state of 40 ICTAS scholars by 2011.

Richard Benson, dean of the College of Engineering, concludes, "Based on detailed analyses of factors that contribute to national rankings and on bench-marking at top-line universities, we already see that Virginia Tech's ICTAS has emerged as a vital vehicle that will carry the College of Engineering and Virginia Tech to a greater height.

"The College of Engineering attributes the success of ICTAS to its entrepreneurial nature. Through collaborative research and discovery, ICTAS presents a case for advancement of humankind through collaborative research."

By Lynn A. Nystrom

FACTS AT A GLANCE

Founding:

The institute for Critical Technology and Applied Science was founded on the premise that the Virginia Tech's existing research strengths should be leveraged and promoted to position the university as a leader in research on the state, national, and international level. Malcolm McPherson, when he was the associate dean for research and graduate studies in engineering, conceived the idea, and he presented the plan to the College of Engineering's Advisory Board for the first time in April 1998. Today, iCTAS has two new state-of-the-art facilities with a third in planning stages. It is on course to become among the top-rated institutes globally in transformative, sustainable technologies geared toward societal needs.

Facilities:

ICTAS A – A 32,000 square-foot building was constructed and equipped with state-of-the-art experimental tools for fabrication and characterization at the nanometer scale, opened in fall 2007.

ICTAS I – A 99,000-square-foot building equipped with exceptional laboratory and office space, opening fall of 2008.

ICTAS II – In design development

Early Funding Successes:

Preliminary funding success that was led by engineering included a \$3.4 million grant from NIOSH for construction safety, a \$1.3 million grant for vehicle technologies, and more than \$9 million (in three different grants) for unmanned vehicles research. At the end of fiscal year 2007, the School of Biomedical Engineering and Sciences, part of ICTAS, had reached a total of \$8.7 million in research expenditures.

Credits:

Dean: Richard C. Benson

Editor and Writer: Lynn Nystrom

Art Director and Designer: Barbara Corbett

Photographers: Jim Stroup and John McCormick Contributors: Christina Daniilidi, Richard Lovegrove, Shari Mueller, Jayme Sheperd and Katie Thacker

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