Engineering Research Centers

— INNOVATIONS —

ERC-GENERATED COMMERCIALIZED PRODUCTS, PROCESSES, AND STARTUPS

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OVERVIEW

A primary driver for the establishment of the Engineering Research Centers (ERC) program by the National Science Foundation in 1984 was to facilitate the transfer of knowledge and technology developed out of the ERCs' research on next-generation engineered systems to U.S. industry. This focus on innovation was and still is at the heart of the ERC–industry partnership.

That partnership has yielded rich dividends. From1985 through 2009, ERCs have produced 1,701 invention disclosures, had 624 patents awarded, granted 2,097 patent and software licenses, and spun off 142 firms with (as of late 2009) a cumulative total of 1,452 employees.

This report captures a subset of the most notable of those innovations. It was compiled from information provided by the ERCs, principals of startup companies spun out of the centers, and from public reports and published databases. The focus is on technologies that have been successfully transferred to industry, where they resulted in products and processes that were, or are about to be, commercialized. Start-up companies generated out of the ERCs are also an important form of technology transfer and a major route to successful commercialization of ERC innovations. Where available, market data on sales (actual and projected), cost savings, market share, etc., are provided. (It should be noted that in many cases such information is considered proprietary and was not available to be reported here.)

Successful ERCs are supported by NSF for 10 years (11 years in the early years of the Program); when they "graduate" from NSF support they are expected to attain self-sufficiency with funds from industry, academe, and other sources. Findings of this study indicate that over time, ERC-generated innovations have begun to take less time to reach the marketplace due to increased Program emphasis on ERCs promoting innovation through start-ups, while there are still many innovations that reach the marketplace only after an ERC has graduated from NSF support.

Over the past 25 years, 48 ERCs (including 3 Earthquake ERCs) have received roughly $1 billion in funding from the ERC program. Although specific market data are difficult to obtain, it is clear even from the numbers reported here that the total downstream market value of ERC innovations to the U.S. economy to date is well into the tens of billions of dollars, with some of the most promising technologies just now poised to begin rapid growth in the real-world market for technological goods and services. And the dollar figures do not even address the enormous benefits of those products to the nation and the world in terms of human health, safety and security, industrial and personal productivity, quality of life, and environmental protection.

The products and processes outlined in this report demonstrate the breadth and depth of research at the ERCs. Sometimes, the impact is obvious and known to consumers worldwide, such as calculations that enabled high-quality video to be compressed to fit on the DVD disks that are now common in living rooms around the world. Often the work is so technical and specialized that the ramifications are lost outside scientific and industrial communities, such as the development of a new method for analyzing proteins that is helping scientists create new drugs and fulfill the promise of human genomics.

ERC research is divided into the four broad technology areas, or "clusters," that comprise subsections of this report. But the fact that each center draws expertise from across academic disciplines and industrial sectors is a key accomplishment of the ERC program. Likewise, the products generated by researchers often reach into varied if related fields. The Manufacturing and Processing section, for example, describes how an academic research effort to reduce the environmental impact of semiconductor production led, through a spin-out company, to a nanotechnology process for depositing metals on silicon—a process that turns out to have broad applications for applying coatings to a wide range of surfaces.

Each section includes advances that contribute to economic progress and improve the quality of life. Quality of Life is, in fact, the specific focus of a Biotechnology and Health Care ERC, where researchers address lifestyle challenges posed by the growing disabled and senior populations. But as is typical of ERCs, work that initially focuses on one community is found to have applications to broader society. An example is a tactile technology designed to help the hearing-impaired enjoy music, but that can add a new sensory aspect to music and enhance the listening experience for everyone.

While the ERC program seeks to solve problems with cutting-edge research, many of the challenges it addresses are as old as the planet itself. Earthquakes are inevitable, but several centers in the Energy, Sustainability, and Infrastructure cluster strive to better understand why and where the disasters will occur, and how cities can better prepare their infrastructure to minimize the impact. ERC innovation also tries to stay ahead of newer issues, such as a center that began its study of how to more efficiently deliver electrical energy across great distances just as the development of a "smart grid" began to be seen as a national and global priority.

The diversity of research and outcomes contained in this report is perhaps best illustrated by considering the physical reach of centers at work in Micro/Optoelectronics, Sensing, and Information Technology. One center's focus is at the nanometer scale, where it seeks to reduce the wavelength of ultraviolet light used in carving ever-smaller circuits onto silicon chips. Another center stretched across the vastness of space to find a novel way to deliver Internet broadband service to areas without wired connections.

The story of ERC innovations is one that will continue to unfold. Therefore, this report will be updated periodically and posted at http://showcase.erc-assoc.org.

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BIOTECHNOLOGY AND HEALTH CARE

ERC FOR EMERGING CARDIOVASCULAR TECHNOLOGIES (ERC/ECT) – Duke University (class of 1987-1998)

The vision of the ERC/ECT was the development of advanced instrumentation systems and techniques that would enable improved diagnosis, therapy, and monitoring of coronary artery disease and its sequelae in the myocardium. The application of these technologies was expected to lead to a more complete understanding of the interrelationship among the metabolic, electrical, and mechanical events of the heart.

Product/Process Successes

Implantable Defibrillators: At the ERC for Emerging Cardiovascular Technologies (ECT), which graduated in 1996, research in antiarrhythmic systems was aimed toward developing high-tech devices to halt or prevent ventricular fibrillation, the primary cause of sudden cardiac death. About 400,000 people succumb to sudden cardiac death annually in the United States alone. The ERC judged in the late '80s that if only 10% of these individuals could be identified to be at risk and have devices implanted, the potential U.S. market would be close to a billion dollars per year and the international market several times larger.

Two of the ERC/ECT's major research breakthroughs in antiarrhythmic systems—improved electrodes and a novel understanding of biphasic waveforms which led to biphasic waveform circuitry—were transferred to the implantable defibrillator industry. Both of these developments reduced the energy needed to defibrillate. This single improvement resulted in five advantages over previous implantable defibrillator technology: (1) reduced tissue damage; (2) reduced device size, allowing for easier implantation; (3) reduced time to charge the device, thus decreasing the time the body is without blood flow during the arrhythmia; (4) extended battery life; and (5) a wider range of patients treatable with implantable defibrillators.

Biphasic waveforms have been adopted by the implantable defibrillator industry. Two companies, Intermedics and Ventritex, working with ERC/ECT researchers, took the research in biphasic waveforms to the stage of clinical testing. Two other companies, Cardiac Pacemakers (CPI) and Medtronic, developed their own biphasic waveform circuitry based in part on this ERC/ECT research. Intermedics also brought to clinical trials the improved electrodes developed by the ERC/ECT. Today, implantable defibrillator companies continue to build on the Center's findings and modify their defibrillators accordingly.

Portable Defibrillators: The same improvements in sensors and electrodes that the ERC/ECT's work brought to internal defibrillators have also been used by industry to design external (portable) defibrillators, used to help people who suffer heart attacks in public places, easier to use and less expensive (about $3000 per unit). A more

efficient and effective power source for delivery of the shock permitted miniaturization of the devices.

3D Ultrasound: The ERC achieved several breakthroughs in sensing and image processing that made three-dimensional ultrasound possible. At the time, this technology was 5-7 years ahead of acceptance by the medical community and insurance companies; now it is ubiquitous, partly as a result of early championing by the ERC/ECT through a startup, Volumetrics Medical Imaging. The worldwide market for this equipment is estimated at $2.7 billion per year.

Startups

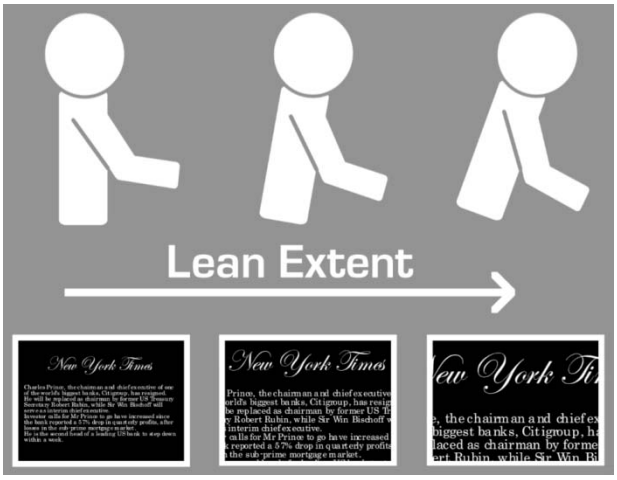
Volumetrics Medical Imaging: In 1990, two ERC faculty formed this startup to build and sell then-revolutionary real-time 3D ultrasound equipment. Volumetrics' machine used parallel processing of ultrasound signals to obtain multiple images simultaneously, allowing doctors to view an organ from four or more perspectives at once. Eventually Royal Philips Electronics (based in the Netherlands) pursued a purchase of the company, but backed out. In 2004 Philips settled a breach-of-contract claim by Volumetrics out of court for EUR $145 million (USD $185M). The 3D technology is in equipment still sold today by Philips and other companies.

QUALITY OF LIFE TECHNOLOGY ERC (QoLT-ERC) – Carnegie Mellon University (Class of 2006)

The vision of the QoLT Center is to develop intelligent systems ranging from individual devices to comprehensive environments that enhance body and mind. These systems will monitor and communicate with a person and understand his/her needs and task goals, compensating for or replacing diminished capabilities appropriately, safely, reliably, and graciously.

Startups

Invynt (invynt.com): The Lean & Zoom system from startup Invynt leverages the increasing use of cameras at computer workstations to measure an operator's natural tendency to lean to see content on the PC's screen. The user is usually leaning to magnify otherwise unseen details. As the software measures a change in the user's profile as they lean toward the screen (and camera), the Lean & Zoom system eases the need to lean further by automatically magnifying the content on the screen.



This system was created and developed by Chris Harrison, a Ph. D. candidate at CMU in the Human-Computer Interaction Institute (HCII) with the

assistance of Anind Dey, a member of the QoLT faculty and Assistant Professor in the HCII. In late 2009 the Lean & Zoom software was nearly ready for deployment, which could be as simple as downloads from a website or store. The startup is in discussion with a number of companies and potential investors.

VibeAttire: Born of a project at the QoLT ERC to enhance the enjoyment of music for the hearing impaired, VibeAttire's patent-pending technology offers new way to listen to music for everyone that adds a sensory aspect not often felt outside clubs or concerts. Carnegie Mellon doctoral student Aubrey Shick created VibeAttire to help the deaf to feel music through wearable devices that take standard audio information and convert it into a vibro-tactile experience.

The first product, a wearable vest, is soon to go on pre-sale via a Web store for $140. A web-based campaign is aimed at the target audience of 15-to-30 year-olds, and local Pittsburg rap-music artist Freestyle has contributed to a video that will be part of the campaign. The market is expected to expand beyond the hearing impaired because of the unique experience of "feeling sound" this vest offers those who can hear.

VibeAttire's motors are removable so that the garment can be washed.

GEORGIA TECH/EMORY CENTER (GTEC) FOR THE ENGINEERING OF LIVING TISSUES (class of 1998-2008)

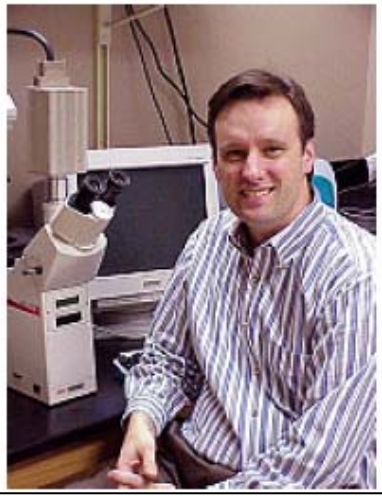
GTEC's mission is to develop the core technologies required to confront the crisis in availability of organ transplants and to help build the tissue-engineering industry, including design concepts and evaluation techniques. The technologies that the graduated and self-sustaining GTEC is developing will create biological substitutes for implantation into the body and/or the fostering of tissue regeneration and remodeling, with the purpose being to replace, repair, maintain, or enhance function.

Startups

ArunA Biomedical (arunabiomedical.com): ArunA creates reliable, robust, and highly scalable human stem cell systems. Capable of reducing drug discovery and early stage

research timelines, its systems are uniquely suitable for a wide range of applications and assays including: cellular model studies, high content screening, developmental studies, RNAi studies and genetic manipulation. The company was founded in 2003 by Dr. Steve Stice. Stice is Georgia Research Alliance Eminent Scholar in Reproductive Physiology at the University of Georgia (UGA), and an active collaborator with Georgia Tech and Emory scientists through GTEC.

The applications of ArunA's technology include replacing animal testing with human cells for water and food safety, for which ArunA received $1 million in funding through the Department of Defense. Other applications include testing for pharmaceutical and biotech safety, as well as potentially developing disease-specific neural stem cells for Alzheimer's, Parkinson's, multiple sclerosis, and oncology. Its commercially available products include human neural progenitor cells, including differentiated human neural cells, induced pluripotent stem cell kits, and mesenchymal progenitors.



Professor and inventor Steven Stice

ArunA has raised more than $3 million in capital, including a recent $2 million sale of convertible debt. ArunA negotiated a license for its neural progenitor technology from the UGA in 2006 and partnered with Millipore to market and distribute the product, which first went on the market in March 2007.

Stice, the leader of GTEC's cell technology cross-cutting group until its graduation in 2008, has received the UGA's Inventor's Award, which was established to recognize an inventor's unique, creative, and innovative discovery that has significantly impacted the research community and industry. Stice also has helped form several other biotechnology companies based on research developments in his lab. Along with Aruna Biomedical, these companies also include Prolinia and Cytogenesis (now a part of BresaGen).

Revitus: Founded by Dr. Stephen Hanson, formerly of Emory University, who also served as president and CEO and a principal investigator in the now-graduated ERC. The company was started in 2001 to develop therapeutic strategies for prevention of heart attack and stroke. Its products were designed to produce safe and specific pharmacological treatment for prevention of thrombotic vascular disorders, including heart attack and stroke. Revitus relocated to Portland, Oregon, where Dr. Hanson is now the Chair of Biomedical Engineering at the Oregon Health Sciences University and Oregon Graduate Institute School of Science & Engineering. Dr. Hanson continues to be involved with GTEC through research projects and collaborations.

Revitus was acquired in 2007 by BioVascular, where five full-time-equivalent employees remain devoted to Revitus research. All together, the company raised more than $17 million in capital.

Orthonics: Dr. Barbara Boyan is an inventor and founder of Orthonics and Dr. Stephen Kennedy is a co-inventor and serves as CEO for the company. Orthonics, founded in 2002, developed advanced biomaterials with the ability to promote bone and cartilage growth and adhesion. Orthonics' technology is based on research from the laboratory of Boyan, the Price Gilbert, Jr. Chair in Tissue Engineering, a Georgia Research Alliance Eminent Scholar, and a member of GTEC's executive committee. The company's technology included an improved hydrogel biomaterial and a novel surface patterning technique used to create a more natural attachment between the artificial material and bone or cartilage tissues. Startup "translational research" funding from NSF was key to GTEC and Orthonics collaborating on a proof-of-concept, preclinical implant study to use the technique to grow new bone. The project was a success. Cartisept Medical bought Orthonics' intellectual property (IP) for $1 million and has raised $20M in venture capital financing to develop a range of products for cartilage therapy.

SpherIngenics: The company was formed in 2007 to commercialize microencapsulated autologous cells into unique injectable microbead products for therapeutic and aesthetic soft tissue augmentation, using technology that was invented in the lab of GTEC's Barbara Boyan. Autologous cells are considered the "gold standard" of implantable materials, since they are the patient's own cells. The company's research has demonstrated that it can encapsulate pre-adipocyte fat cells in microbeads and maintain 95% cell viability.

The company has received over $200,000 in VentureLab and Coulter grants and $200,000 in DOD awards. President and CEO L. Franklin Bost has more than 30 years of industry experience and is also currently Director of Design Education in the Georgia Tech/Emory Department of Biomedical Engineering.

Ontogenesys Biotechnologies: This company was launched in 2009 by Jeff Caves, a postdoctoral fellow at Emory. It acquired IP developed by Emory vascular surgeon Elliot Chaikof and previously held by BioSequent, which had received a $15,000 VentureLab grant from the Georgia Research Alliance to evaluate the commercial potential of recombinant biomaterial devices for soft tissue repair, replacement, and augmentation.

SYNTHETIC BIOLOGY ENGINEERING RESEARCH CENTER (SynBERC) – University of California at Berkeley (class of 2006)

SynBERC is developing the foundational understanding and technologies that will allow engineers to use standardized biological components to design and build integrated biological systems for a wide range of purposes.

Product/Process Successes and Startups

Curing Malaria (Amyris Biotechnologies): The whipsawing of prices and supplies of artemisinin have threatened its central role as the only effective treatment for malaria, a pernicious disease that kills more than a million people annually in the developing world. By engineering yeast and *E. coli* bacterium, Dr. Jay Keasling, Director of the Synthetic Biology Engineering Research Center (SynBERC) has developed a method of semi-synthetically producing artemisinic acid, which is then processed into artemisinin.

Artemisinin is used as the key component in multiple-drug therapies to cure malaria. Keasling's method for producing artemisinic acid will make the treatment of malaria affordable in the developing world, where supplies of artemisinin are short and prices high, with treatments sometimes costing a prohibitive $20 per patient. The engineered yeast is already capable of producing artemisinic acid much more efficiently than can be done through natural sources. But the process needs to be optimized and scaled-up for industrial production to reduce the cost of therapies significantly below their current prices. So in 2008 Keasling's spinoff company, Amyris Biotechnologies, transferred its artemisinin technology to global pharmaceutical firm Sanofi-Aventis, which is working on large-scale development of the product. The process is expected to result in marketable quantities of artemisinin by 2011, and full-production in 2012.

Keasling's early underlying work in this area was funded by the Engineering Directorate's metabolic engineering program. The SynBERC ERC has provided the synthetic biology foundation—a large number of re-usable synthetic parts—upon which the translation of this innovation to practical use is being realized. The Bill and Melinda Gates Foundation has been instrumental in the process, providing more than $42 million in total grants to UC-Berkeley for basic and translational research, to Amyris for process development, to Sanofi-Aventis for process scale-up, and to a non-profit U.S. corporation, the Institute for One World Health, for delivery to malaria-afflicted areas in Africa.

SynBERC and UC-Berkeley developed the novel intellectual property model for this large-scale project in the emerging synthetic biology field

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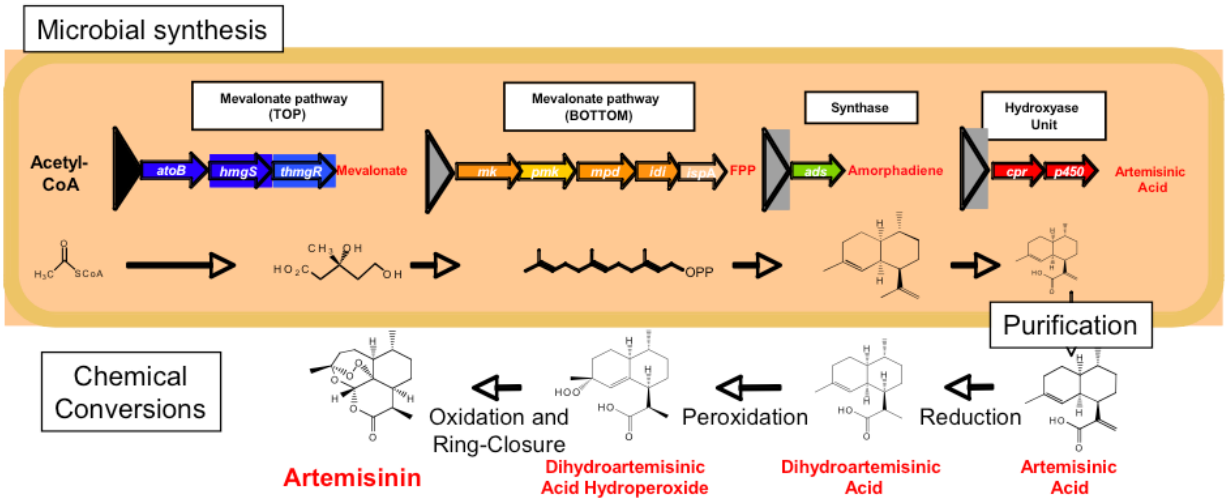


Rapid Genome Engineering (LS9): The traditional approach to genetic engineering is an arduous process in which scientists alter a cell's metabolic system, but only one gene at a time. Not only are outcomes hard to predict, making changes to a gene involved in one reaction may lead to undesired effects. A research team supported by SynBERC and led by Dr. George Church has developed a new technology that can make dozens of changes to a bacterial genome in one sweep, which they have called called multiplex-automated genomic engineering, or MAGE.

Such high-throughput and automated methodologies can rapidly and efficiently make both site-specific and large-scale manipulations of genomes possible. The methods combine large-scale DNA synthesis techniques with engineered recombination strategies to develop fast and cost-effective construction of *de novo* gene systems, or "cellular chasses." Just as in developing the computer it was important to integrate all of the devices (motherboard, disk drive, input-output devices) into a chassis, it is important in the development of synthetic biology to devise a cellular chassis into which we can add the devices constructed in other SynBERC research thrusts.

The MAGE technology, for one, has promising applications to the work at LS9, a biofuels company co-founded by Church. LS9 intends to use the technology to accelerate development of bacteria that can produce clean-burning, low-cost, and renewable fuels and chemicals. In the fall of 2009, LS9 announced it had raised $25 million in a third round of venture funding.

ERC FOR COMPUTER-INTEGRATED SURGICAL SYSTEMS TECHNOLOGY (CISST) – Johns Hopkins University (class of 1998-2008)

The graduated and self-sustaining CISST is developing novel computing methods, interfacial technologies, and computer-integrated surgical (CIS) systems. By extending human surgeons' ability to plan and carry out surgical interventions more accurately and less invasively, CIS systems will address a vital national need to greatly reduce costs, improve clinical outcomes, and improve the efficiency of health care delivery.

Product/Process Successes

Image-guided Needle Placement: The value of image-guided needle-based therapy and biopsy for use in dealing with a wide variety of medical problems has been proven. However, both the accuracy and the procedure time vary widely among practitioners of most systems currently in use. Typically, a physician views the images on the scanner's console and then must mentally relate those images to the anatomy of the actual patient. A variety of virtual reality methods, such as head-mounted displays, video projections, and volumetric image overlay have been investigated, but all these require elaborate calibration, registration, and spatial tracking of all actors and components. This creates a rather complex and expensive surgical tool.

Researchers at the recently graduated ERC for Computer-Integrated Surgical Systems and Technology, in collaboration with Dr. Ken Masamune of Tokyo Denki University in Japan and the Siemens Corporation, have developed an inexpensive 2D image overlay system to simplify, and increase the precision of, image-guided needle placements using conventional CT scanners. The device developed at the CISST ERC consists of a flat LCD display and a half mirror, mounted on the gantry. When the practitioner looks at the patient through the mirror, the CT image appears to be floating inside the patient with correct size and position, thereby providing the physician with two-dimensional "X-ray vision" to guide needle placement procedures.

Researchers have conducted cadaver studies for several applications with a clinically applicable device. Dr. Laura Fayad at the Johns Hopkins Medical Institution has also

performed joint arthography of the shoulder and hip joints, achieving millimeter-level accuracy in needle placement. Institutional Review Board applications for the CT-guided system and an MRI-compatible prototype are under development.

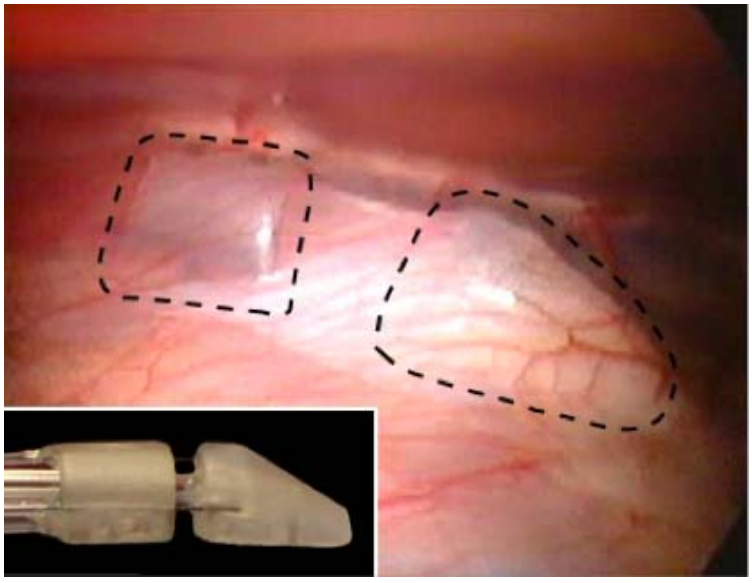
Startups

Heartlander Surgical (heartlandersurgical.com): Open-heart surgery that involves "cracking the chest" is about as invasive as a medical procedure can get. Even the newer, less-invasive invasive procedures require deflating a lung. A technology that eliminates these risks would offer a giant step forward in cardiac surgery.

At the CISST, Dr. Cam Riviere and colleagues at Carnegie Mellon University (CMU) have developed HeartLander, a small, minimally invasive robot that can move along the surface of the heart and navigate to any desired work site under the control of a surgeon, who uses it to perform surgery. It's part of the CISST's focus on computing methods, surgical systems, and technological aids that can revolutionize surgical procedures.

Using suction to adhere to the beating heart, the HeartLander crawls like an inchworm across the surface, just beneath the enveloping pericardium. The autonomous movement is an important advance over existing cardiac surgical aids that are manipulated at the end of a stiff wand. The device incorporates a videoscope to provide visual feedback to the surgeon, who controls it through a joystick interface. The 8mm-diameter device has a flexible working channel through which various tools can be introduced for such surgical procedures as electrode placement, tissue ablation, drug or tissue injection, and anastomosis. Because the HeartLander can be used with local or regional anesthesia instead of general anesthesia, it could for the first time enable ambulatory outpatient heart surgery.

Heartlander Surgical was formed to commercialize the surgical robot. In 2006, the device was demonstrated on a closed-chest beating pig heart—a typical simulation of surgery on a living human heart. The Heartlander device since has undergone nearly 25 trials on pigs to refine various sensing and therapy delivery approaches. Led by Dr. Dwight Meglan, the company continues to evolve the system with a particular focus on arrhythmia therapy delivery at this point. Heartlander is in discussions with several device companies who are interested in using HeartLander as their means of therapy delivery. CMU is a minority partner in the venture, which is capitalized with private funds.



The HeartLander uses suction to traverse the heart's surface beneath the pericardial sac.

BIOTECHNOLOGY PROCESS ENGINEERING CENTER (BPEC) – MIT (class of 1985, reestablished in 1994, graduated in 2005)

BPEC emphasizes a fundamental interdisciplinary approach to integrating molecular and cell biology with process engineering, with the goal of creating advanced biological technologies, focusing on protein and nucleic acid therapeutics. Throughout its 20-year history as an ERC, its primary research focus evolved from therapeutic protein biotechnology to therapeutic gene biotechnology.

Product/Process Successes

Bioprocess Technologies: Advances made in mammalian cell bioprocess technology and protein therapeutics made by the Biotechnology Process Engineering Center (BPEC) have enabled the development of a wide range of new pharmaceuticals. In its first ten years as an ERC, these advances contributed to the following major impacts of BPEC on its industrial partners:

- Copyrighted the *BioDesigner* for bioprocess simulation, leading to the efficient design and synthesis of bioprocesses. This algorithm was licensed to a start-up company, Intelligen, and is used presently by biotechnology companies worldwide for bioprocess simulation as well as in universities for course teaching.
- Rational medium design based on fundamental principles in stoichiometry, biochemistry. and metabolism to increase cell viability and prolong cell culture times in animal cell culture systems, increasing the product concentration. Many companies now employ the algorithm from this research in the manufacture of mammalian cell products.
- Developed methodologies for the characterization of glycoprotein quality, with special emphasis on sialic acid content of therapeutic glycoproteins. Successfully demonstrated means to increase sialic acid content in recombinant glycoproteins, thus helping industry to maintain protein quality during manufacturing.

BPEC Graduates Are Leaders in Biotech Industry: The BPEC has cross-trained hundreds of students in engineering and biology. BPEC alumni now occupy positions of leadership in nearly every major biopharmaceutical company, such as Genentech, Amgen, and Biogen-IDEC, and also at many pharmaceutical companies, such as Merck, Wyeth, and Bristol Myers Squibb.

BPEC alumni at Genentech, for instance, played key roles in bringing new cancer therapies to market. These new monoclonal antibodies, named Rituxan^{R}, Herceptin^{R}, and Avastin^{R}, kill selected cancer cells without causing the broad-scale, systemic cell damage/death of traditional chemotherapy. BPEC alumni not only helped develop new high-titer, fed-batch manufacturing processes for these drugs, they also helped design and build new manufacturing plants in California, some of the largest and most automated plants of their type in the world.

BPEC alumni at Merck, as another example, have played key roles in the global battle against AIDS. Back in the early 90's, BPEC alumni at Merck manufactured parts of the

AIDS virus as drug screening targets. Merck then tested their library of chemicals to see if any could disrupt the function of these virus targets. They found a promising candidate molecule, one that inhibited the activity of the HIV protease enzyme, but it was among the most difficult molecules that the pharmaceutical industry had ever attempted to synthesize. From this work emerged the current protease inhibitor drugs that are used to combat HIV.

Several BPEC alumni, as members of the process team, developed a new manufacturing process and played key roles in the design and start-up of a new manufacturing facility in Elkton, Virginia. The new drug Crixivan^{R}, when combined with older AIDS drugs, could clear the AIDS virus from the blood stream of many victims, and allow them to lead productive lives. It is not a cure, however. Other BPEC alumni at Merck are working on new AIDS vaccines. Their recent success with many other vaccines, including ones for Hepatitis A and chicken pox, provide hope that we might one day have an effective AIDS vaccine.

Startups

PerSeptive Biosystems: Noubar Afeyan, one the first BPEC Ph.D. graduates, founded and built this company in 1991 to commercialize perfusion chromatography for analyzing proteins. Company revenues grew from $1 million in 1991 to around $100 million in 1997. PerSeptive merged with PE Corporation, the former Perkin-Elmer Corp., in a 1998 transaction valued at $360 million. Later, while a Senior Vice President at PE, Afeyan initiated and managed the creation of Celera Genomics, a subsidiary of PE. Celera later completed the sequencing of the human genome.

Intelligen (intelligen.com): Demetri P. Petrides, a BPEC Ph.D. graduate, founded Intelligen in 1991. Petrides is President and CEO. The company licensed bioprocess simulation software from BPEC, and in turn licenses this technology to companies around the world. Intelligen targets the biotechnology, pharmaceutical, specialty chemicals, and consumer goods industries and lists more than 200 companies and academic institutions as customers. The company has four employees and annual sales of about $1.4 million, according to ReferenceUSA.

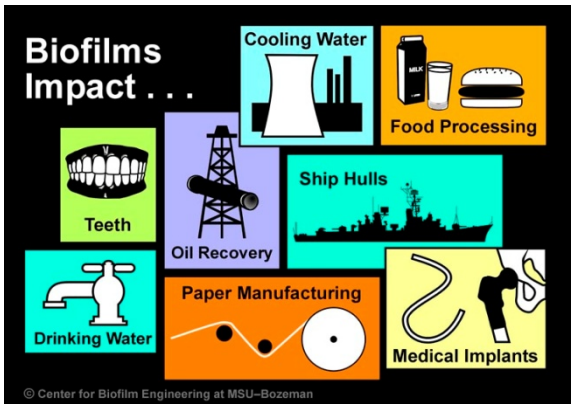
CENTER FOR BIOFILM ENGINEERING (CBE) – Montana State University (class of 1990-2001)

The mission of the graduated and self-sustaining CBE is to advance the basic knowledge, technology, and education required to understand, control, and exploit biofilm processes.

Product/Process Successes

Biofilm Control by Signal Manipulation: At the time NSF funded this ERC it was known that all engineered aqueous systems suffer from the deleterious effects of biofilm formation, which causes fouling, corrosion, and filter blockage in industrial systems and much more profound problems in the human body, such as chronic infection from medical device implants and wounds. Marine systems are adversely affected by bacterial fouling, and by subsequent macrophyte colonization; and the increased energy costs of

propelling fouled hulls through the water costs the US Navy billions of dollars per year. Little was known about how to combat the formation of biofilms.

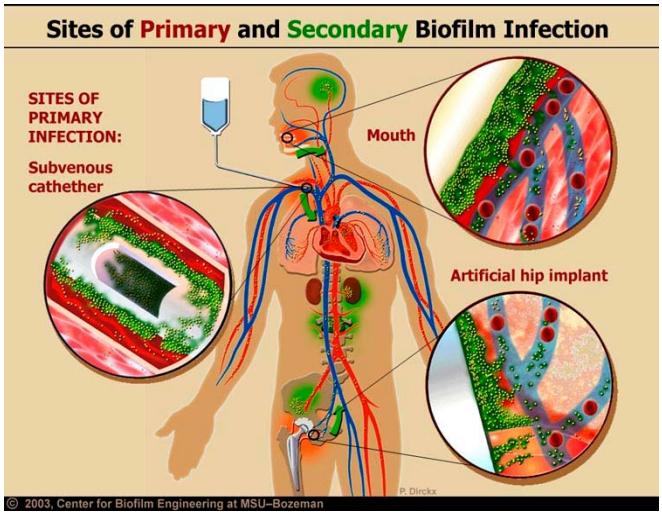


In the late 1990s, when researchers at the Center for Biofilm Engineering discovered that biofilms are composed of cells in matrix-enclosed micro-colonies and that these micro-colonies form "towers" interspersed between open water channels, they concluded that a system of chemical signals must control the development of these complex communities. They were the first to show in a April 1998 *Science* paper that biofilm formation in Gram-negative bacteria is controlled by chemical signals (acyl homoserine lactones, or

AHLs) that also control quorum sensing processes by which bacteria "sense" the number of cells present in a given ecosystem. Subsequently, the CBE described many different signals of this type. Because of this discovery the ERC and the medical research community began to realize that many chronic diseases, such as cystic fibrosis, prostatitis, and chronic wounds, are the result of biofilm formation.

Biofilm control signals have subsequently been identified in many economically important organisms and several start-up companies have sought to find and commercialize specific signal blocking analogues in order to control biofilm formation. The CBE was awarded a patent on biofilm control by signal manipulation and a start-up firm, BioSurface Technologies, was spun off to capitalize on this technology.

Biofilm as a Causative Agent in Chronic Wounds: Together with Dr. Randy Wolcott of the Southwest Regional Wound Care Clinic in Lubbock, TX, the CBE has shown that chronic wounds, such as diabetic lower extremity ulcers, are due to persistent biofilm infections. Preliminary work in this field led to the award of a NIH grant to the CBE to continue to develop models for the in-vitro study of chronic wounds and assess the efficacy of anti-biofilm agents.



Biofilm Assessment Methodologies: The CBE has been instrumental in standardizing methods of measuring biofilms. This impacts how commercial products are evaluated by regulatory agencies, how health-related guidelines are enforced, and how researchers choose assays to quantify attached cell growth. The CBE

has led activities within standard-setting organizations such as ASTM and the American Dental Association, as well as within regulatory agencies such as EPA and FDA, to propose statistically valid methods for biofilm assessment and quantification.

Startups

BioSurface Technologies (imt.net/~mitbst) Former CBE research engineer Bryan Warwood started BioSurface Technologies (BST) in 1995. BST has licensed biofilm growth reactor technology developed at the CBE and manufactures reactors for the academic and industrial market. BST is the largest "process flow" biofilm reactor company in the US, with gross annual sales of approximately $150,000 and a 10% sales growth rate, serving an international customer base.

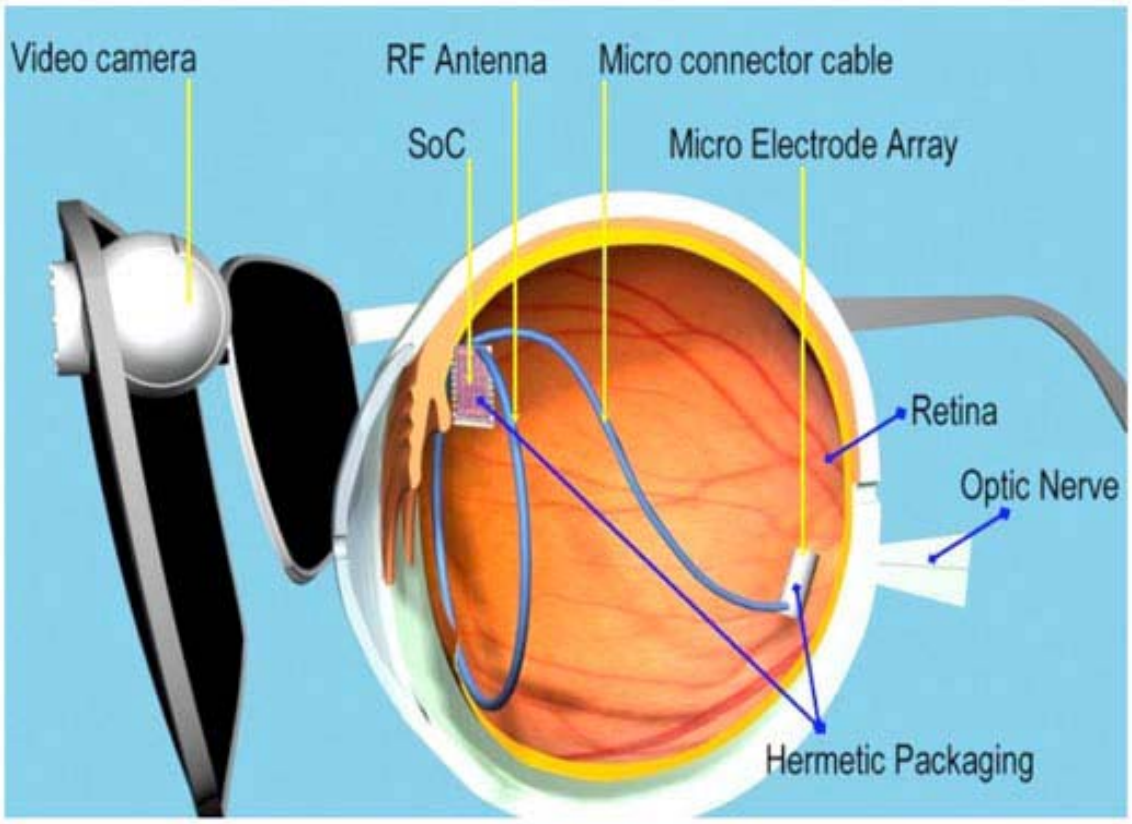
ERC FOR BIOMIMETIC MICROELECTRONIC SYSTEMS (BMES) – University of Southern California (class of 2003)

This ERC's vision is to develop the science and engineering of novel biomimetic microelectronic systems (BMES) based on fundamental principles of biology. These systems allow bi-directional communication with tissue, and by doing so enable implantable/portable microelectronic devices to treat presently incurable human diseases such as blindness, paralysis, and memory loss.

Product/Process Successes

Prosthetic Retina: Millions of people who have lost their sight due to degenerative eye diseases may one day see again, thanks to recent advances toward engineering an artificial retina at the ERC for Biomimetic Microelectronic Systems. Dr. Mark Humayun, Director of the BMES at USC, and his research group have developed a prosthetic device that enables previously blind people to perceive light and patterns.

The system works with neural pathways that, despite disease to other parts of the eyes, in many cases remain healthy and can still carry information to the brain. Electrodes surgically implanted and attached to the retina transmit information acquired from an external video camera that is mounted on a pair of eyeglasses worn by study volunteers. The visual information is translated to electrical signals that the brain is able to interpret as imagery.



A 60-electrode grid that is surgically implanted and attached to the retina. These electrodes transmit information acquired from an external video camera that is mounted on a pair of eyeglasses worn by study volunteers.

The prosthesis has reached a second generation, called the Argus II Retinal Prosthesis System, that in the fall of 2009 was undergoing FDA-approved testing in some 40 volunteers worldwide. The Argus II includes a 60-electrode grid implant that enables some patients to perceive shapes and lights, with volunteers saying they can point to a full moon or see a line moving on a computer screen. Researchers believe that in the not-too-distant future they will be able to implant a grid with more than 1,000 electrodes, which could enable large-print reading and adequate face recognition vision as well as a 20-degree visual field.

The device is a collaborative effort between USC and Second Sight Medical Products, which manufactures the implant. The retinal prosthesis has several components, some inside and some outside the eye. External components include a small camera, image processing unit, and a sending unit. Implanted components include a bi-directional antenna, hermetically packaged electronics including a novel mixed-signal “system on a chip” (SoC), and a multi-channel electrode array. The implanted electronics handle power management; receive, process, and transmit data; and send the output signals to the optic nerve. The ultimate goal is to design a fully implantable system, with patients enjoying near full restoration of sight. The potential market for such a device would be in the billions of dollars worldwide.

Startups

Replenish (replenishinc.com): Many diseases of the eye can involve repeated injections that can put patients at risk for tears, infection, and other complications. A refillable and wirelessly programmable reservoir and pump that would be implanted on the outside of the eye would more safely deliver repeated treatment through a single, tiny tube into the eye. The pump is based on technology developed by ERC researchers Yu-Chong Tai and Mark Humayun in work originally supported by industry funding through the BMES ERC and later by NIH and foundation grants and in collaboration with the California Institute of Technology. Work on the device by Ellis Meng, an assistant professor of biomedical and electrical engineering at USC, was cited in a 2009 *Technology Review* article that named her one of the world's "Top 35 Innovators" under the age of 35.

Replenish was founded in 2007 to further develop and commercialize the technology, which will enter trials for FDA approval in 2010. The pump can deliver medicine to the eye to treat glaucoma or age-related macular degeneration, with wireless signals able to change the timing and quantity of doses. The Replenish device can last more than five years before replacement—much longer than most current treatments. Replenish is backed by a $10 million investment from a large pharmaceutical company.

VANDERBILT-NORTHWESTERN-TEXAS-HARVARD/MIT (VaNTH) ERC FOR BIOENGINEERING EDUCATIONAL TECHNOLOGIES – Vanderbilt University (class of 1999-2007)

This ERC was established to experiment with the use of the ERC construct in stimulating the advancement of curricula and learning technology needed to support biomedical engineering education and the emerging field of biological engineering.

Product/Process Successes

Springer Partnership: Commercial publisher Springer Science + Business Media signed a partnership agreement with VaNTH to develop a series of textbooks, reference works, and research monographs in the field of bioengineering. The works include a text on biotransport based on VaNTH concepts authored by Drs. Robert Roselli of Vanderbilt University and Kenneth Diller of the University of Texas. In addition, Thomas Harris of Vanderbilt edited a volume of the "Dictionary of Biomedical Engineering" that presented definitions of terms in biomedical engineering and the VaNTH taxonomies of knowledge in the field. Also included was a series of monographs in bioengineering educational advances edited by VaNTH's Dr. Robert Linsenmeier of Northwestern University.

This series seeks to identify and publish texts in bioengineering that will be based on the VaNTH educational designs. In this way, VaNTH will broadly impact the field of bioengineering education.

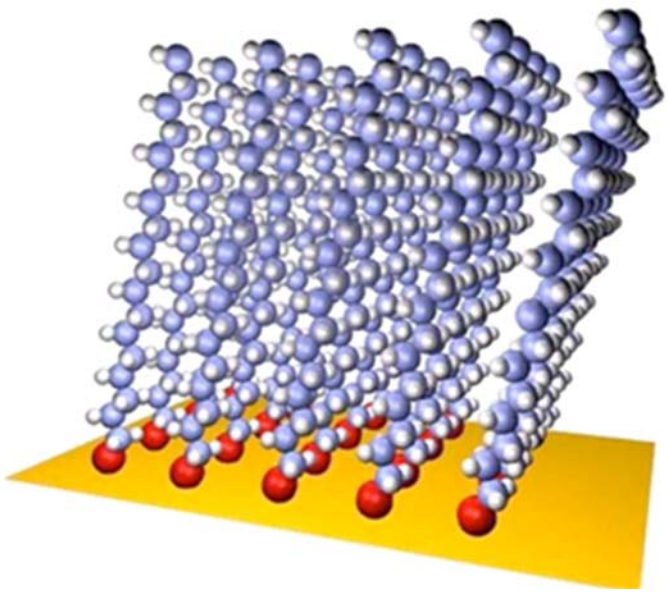
UNIVERSITY OF WASHINGTON ENGINEERED BIOMATERIALS ERC (UWEB) – University of Washington (class of 1996-2007)

The self-sustaining graduated ERC UWEB's objective is to develop a new generation of biomaterials that exploit specific biological recognition mechanisms, being designed so that upon implantation they will heal in the body in a facile, physiologically normal manner.

Startups

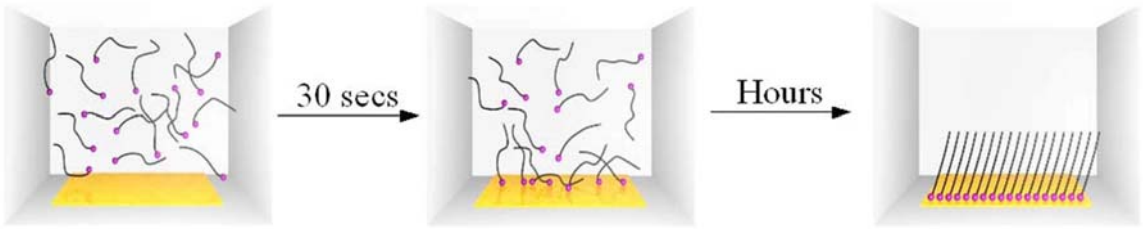
Asemblon (asemblon.com): Developing alternative fuels for transportation is key to achieving greater energy self-sufficiency in the United States. Hydrogen-fueled cars offer a potential option but there are major challenges in efficiently storing and distributing the fuel. Researchers at the now-graduated Engineered Biomaterials ERC have formed a start-up company that is tackling these issues.

Asemblon was initially created to produce and market a biomaterials-related invention that has applications in biotechnology, molecular electronics, and other areas. Called self-assembled monolayers (SAMs), the ordered molecular assemblies are formed by the adsorption of an active surfactant onto a solid surface. The thin crystalline films are an ingeniously simple, yet powerful approach to modifying the surface properties of a material. Asemblon has developed a revenue stream from catalog sales of proprietary and specialty alkyl thiol reagents, a leading form of SAMs.



Self-assembled monolayer

The firm discovered that a SAM assembly also has significant potential for hydrogen storage. It allows hydrogen to be chemically stored and released to generate energy when it is needed. Once hydrogen has been released, the material can be recycled and re-used for hydrogen production. Asemblon has established a separate division aimed at optimizing hydrogen storage capacity and release through its patented process, which helped the company raise $2.9 million in new financing in early 2009. The company has raised $11 million in financing since its founding in 2005, currently has about 30 employees, and ResourceUSA reports annual sales of about $3 million.

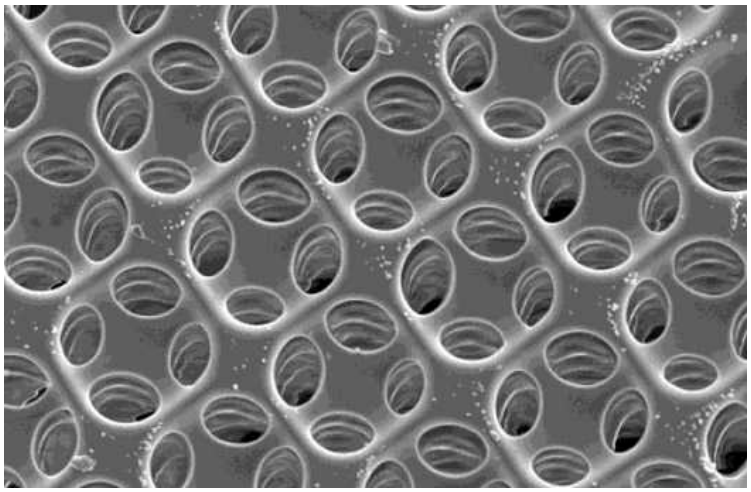


Schematic representation of the self-assembly process as alkanethiols come down onto the gold surface, begin to organize, and pack into an ordered monolayer.

Healionics (healionics.com): In partnership with the UW Tech Transfer Office, Healionics incorporated in March 2005. The founders are Buddy Ratner, Ceci Giachelli, Joan Sanders, Paul Bornstein, Miqin Zhang, and Andy Branca, all faculty associated with the UWEB ERC. Healionics is also being guided by the UWEB Consortium sponsors regarding prioritization of product target applications in medical devices.

Healionics began with a biomedical breakthrough in research by Dr. Ratner and Dr. Andrew Marshall: i.e., discovering the "sweet spot" in a precise pore size and geometry that allows biomaterial to promote the acceptance of biomedical devices within the body. The result is based on UWEB technology and is known as STAR (Sphere Templated Angiogenic Regeneration) biomaterial, a precision-engineered three-dimensional biomaterial scaffold that is designed to heal around a medical device and promote acceptance in the body.

Healionics in March 2009 announced the sale of its first commercial product featuring Healionics' STAR biomaterial. The product, TR-ClarifEYE, an innovative veterinary glaucoma implant marketed by TR BioSurgical, LLC (TRBIO), was launched in April 2009. In addition to the veterinary ophthalmic market, Healionics currently has numerous research agreements in place evaluating the STAR biomaterial in multiple human market applications including aesthetics, obesity management, diabetes care, advanced wound care, chronic pain management, end stage renal disease, and long-term infusion care.



SEM image of crystalline pattern on STAR material surface.

The technology is also being developed further at the UW with funding from the Coulter Foundation Translational Partnership for use in bone repair and from the State of

Washington Technology Center Research and Technology Development program for percutaneous access devices, with additional funding from the SBIR program at NIH.

Its successes enabled Healionics to raise more than $4 million in financing during 2008.

Inson Medical Systems (insonmed.com): Inson was formed in 2007 to develop a single platform: an ultrasound-regulated, pulsatile controlled-release drug delivery system. The company's initial efforts are focused in the area of ophthalmology for both human and veterinary patients, with long-term applications for insulin, antibiotics, and cancer chemotherapy, among others. The technology can capitalize on the fast-growing market for alternatives for oral drug delivery. Market analysts predict that the demand for new drug delivery systems will increase by over 10% annually to $132 billion in 2012, with non-oral routes-of-administration expected to provide the strongest performance, with 15% annual growth.

The Inson Solution makes use of an innovative and patented "rate-limiting-barrier" technology that can be "grown" onto the surface of virtually all types of approved polymeric biomaterials. The design allows Inson to craft small, soft, moldable drug depots that can be easily implanted. The Inson Solution makes it possible to place medication in sites that are too small for traditional on-site methods such as the interior of the eye, brain, and spine. The device can deliver a constant dosage of medication over a period ranging from 24 hours to 45 days. A more stringent self-assembled monolayer formulation that Inson has licensed completely blocks all drug release until an external stimulus is applied via ultrasound.

Inson's antibiotic delivery intraocular lens device is also being further studied at UW with funding from the Coulter Foundation Translational Research Partnership.

Ratner Biomedical (ratnerbiomedical.com): Originally formed as a holding company, Ratner Biomedical (RBG) was formed by Seattle entrepreneur Chris Somogyi, Dr. Buddy Ratner, and Stephen Quinn. Mr. Somogyi had founded and led four other technology companies based on in-licensed technology developed at research universities. RBG took an option on more than 20 US and foreign patents, issued and pending, based upon UWEB ERC technology.

The holding company's spinoffs include Inson Medical and Healionics, and more recently Calcionics and BEAT BioTherapeutics. Calcionics, based upon UWEB Deputy Director Cecilia Giachelli's osteopontin technology (a biocompatible material that can be used in heart valves), is just moving into large animal studies for vascular disease under the direction of a seasoned biotechnology entrepreneur as CEO and is in partnering discussions with a major biotechnology firm. BEAT is the development-stage company and is focused on treatment of heart disease with stem cells and engineered biomaterial scaffolds.

Ratner Biomedical itself has several target areas including engineered biomaterials and coatings, tissue engineering and regeneration, pharmacologic therapy, and drug delivery. The company is focused on regenerative medicine and tissue engineering and has licensed its first technology.

MANUFACTURING AND PROCESSING

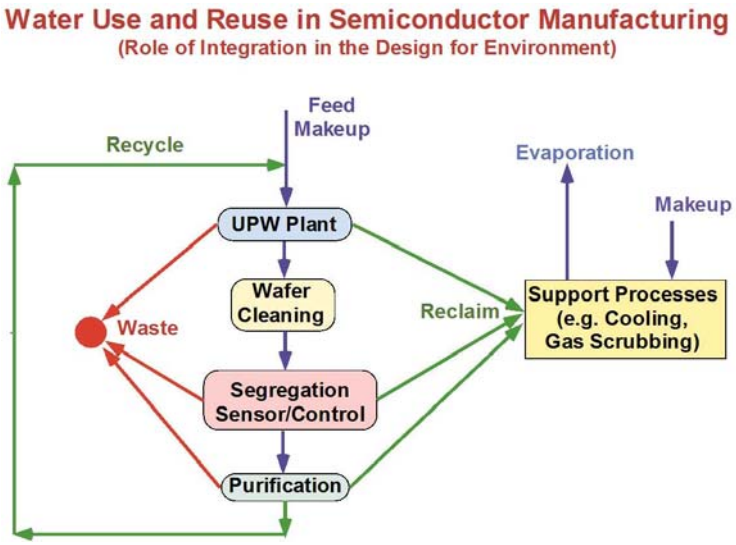
ERC FOR ENVIRONMENTALLY BENIGN SEMICONDUCTOR MANUFACTURING (CEBSM) – University of Arizona (class of 1996-2006)

This is ERC was jointly support by NSF and the Semiconductor Research Corporation to address environmental challenges posed by the manufacture of semiconductor technology manufacturing.

Product/Process Successes

Reducing Water Use in IC Manufacturing: The semiconductor industry's use of large quantities of highly purified water in integrated circuit (IC) chip manufacturing is not only costly but also has large potential environmental implications. Along with its partners, the CEBSM set up a unique physical and simulation testbed facility that has allowed researchers to devise improved water conservation and recycling tools and techniques for IC fabrication. The goal has been to provide technology that would make it possible to reduce water usage by 10% to 60%, depending on the fabrication technology being used. Achieving it has required a series of breakthroughs in water purification methods, use reduction, recycling, and reuse of water.

Some of the conservation and resource management techniques developed at the facility have already been transferred to industry and are in use, saving between $250,000 and $2,000,000 annually at each manufacturing site. This research has received a number of high-level national and international awards, including from Semiconductor Equipment and Manufacturing International (SEMI) and the Semiconductor Research Corporation (SRC), which has recognized the contributions as "major innovations that have significantly impacted industry and society."



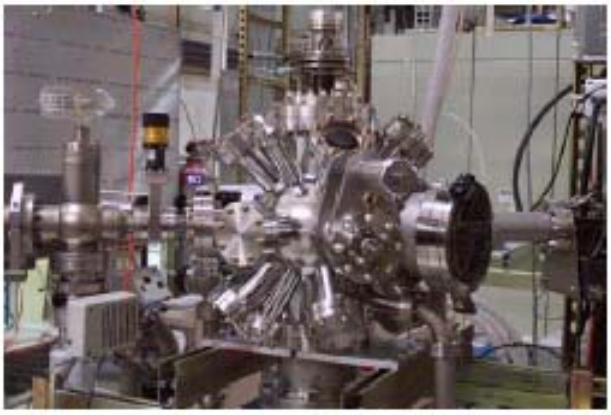
New Sensor Measures Contamination at the Nano-scale: The CEBSM has developed a new sensor and metrology technology, the Electro-Chemical Residue Sensor (ECRS). This is the first and the only sensor technology that can give in-situ and real-time contamination measurement in nano-structures. It is a major breakthrough that would support industry in controlling contamination, a critical problem that is a show-stopper in nano-manufacturing. A start-up company, Environmental Metrology Corporation, was

established to commercialize the technology.

Supercritical Solvent Reduces Environmental Impact of IC Manufacturing: Solvents are used in many industries to clean and transport corrosive chemicals during production, including the manufacture of computer chips, but are not part of the finished product. An industry goal is to lessen the expense and environmental damage caused by handling and disposing of these chemicals. "Supercritical" fluids are used commercially to replace conventional solvents to decaffeinate coffee, synthesize polymers and pharmaceuticals, create microelectromechanical structures, and dry-clean clothing, among other uses. Supercritical fluids have some special properties: They are easily separated from other chemicals and penetrate structures of any size or shape.

Anthony Muscat, a University of Arizona professor with CEBSM, developed a new process using supercritical carbon dioxide ($scCO_2$) in the manufacturing of microelectronic devices. This novel approach replaces standard halogenated solvents—which have many drawbacks—with a chemical that is safe, low-cost, and recyclable and that doesn't cause waste disposal problems. This pressurized form of carbon dioxide can be easily prepared and is already present in large quantities in the emissions from microchip fabrication plants. The $scCO_2$ fluid also has the desirable properties of both liquids and gases and is much less costly than conventional chemicals. Also, its properties allow new ways of depositing and patterning organic films as well as cleaning microstructures. Combining the $scCO_2$ with novel deposition and lithographic technologies is an effective way to create structures with very fine features. The Center used $scCO_2$ to restore a new dielectric film after patterning, showing that this film could be used in computer chips.

Several chip manufacturers are testing and validating the industrial use of $scCO_2$, and the December 2003 edition of *Scientific American* recognized Professor Muscat as one of the 50 people in the nation who contributed the most that year to the advancement of technology in science, engineering, commerce, and public policy. The CEBSM's ongoing work on $scCO_2$ use will continue to advance the technology of computer chip manufacturing in ways that are environmentally sound.



ERC experimental testbed for research on novel cleaning methods and benign solvents.

Startups

GVD Corp. *(*gvdcorp.com): Currently, in the manufacturing of semiconductor and nano devices, various materials are deposited in layers and then almost completely removed after patterning, in what is called "subtractive processing." Research at the CEBSM laid the groundwork for a more efficient "additive processing" approach that promises to

improve performance and lessen the materials and energy use and waste in semiconductor manufacturing.

In conjunction with Stanford and UC Berkeley, ERC researchers at CEBSM made a major breakthrough: They developed a new selective deposition process in which metals are added directly to the substrate to form the gates. Working with Cornell and the Massachusetts Institute of Technology (MIT), they also developed new photo-imageable materials. Together, these new approaches eliminate four steps in the chip manufacturing process that waste energy, materials, and water. As a result, the new process is also much more environmentally friendly and less expensive than the process it replaces.

An ERC faculty member from MIT, Dr. Karen Gleason, and two of her former graduate students, Dr. Hilton Pryce Lewis and Dr. Kenneth K.S. La, both graduates of the CEBSM, founded startup firm GVD Corp. to commercialize the new film deposition technology developed at the ERC by Gleason's group. In addition to its original intended application in environmentally benign semiconductor processing, this technology has various other applications and can be used for novel thin films, coatings, and novel membrane materials with unique porosity characteristics.

GVD is producing engineered polymer coatings that are unattainable using conventional technologies. GVD’s technology is uniquely suited to meet the growing demands for super-thin coatings for medical devices, membranes, textiles, and consumer goods as well as a wide range of other applications, both every day and cutting edge. GVD’s technology can create dramatically improved products as well as brand new products for its customers.

The company has annual sales of $7.2 million and nine employees, according to ReferenceUSA.

Araca (aracainc.com): Araca was founded in September 2004 by Ara Philipossian, who was then leading the ERC's thrust area on the development of environmentally benign planarization technology. Araca's head office is in Tucson, Ariz., with branch offices in Mesa, Ariz., San Jose, Calif., and Kanagawa, Japan. The company's primary focus has been on the commercialization of ERC fundamental research on the development of technology for environmentally benign Chemical Mechanical Planarization (CMP) processes with lower usage of chemicals and energy. Araca is currently co-sponsoring and conducting research and development in collaboration with the ERC.

The company manufactures, in collaboration with Fujikoshi Machinery Corp. of Japan, state-of-the-art 200 and 300-mm polishers capable of real-time measurement, analysis, correlation, and reporting of shear force and down force. It also manufactures fully instrumented testers for characterizing asperity-level mechanical properties of pads and cleaning brushes.

Araca has eight employees, according to Dun & Bradstreet.

Environmental Metrology Corp. (env-metrology.com): EMC was founded in 2003 by CEBSM faculty members Bert Vermeire, Doug Goodman, and Farhang Shadman to provide new and innovative metrology solutions. EMC’s technology conserves valuable process chemicals used in semiconductor manufacturing such as Ultra Pure Water and

Supercritical CO_2 while interfacing easily into the standard manufacturing flow. EMC has utilized ERC fundamental research results and has developed a novel sensor technology that is used by several major companies; SEMI selected this sensor as a "Product of the Year" for 2009. It received recognition in a special ceremony and event at the annual SEMICON West in July 2009 in San Francisco.

Cambridge Metrology Inc: Professor Kim Kimerling and Postdoc Jurgen Michel at MIT's Materials Science Department started this company in 1999 based on a new technology for metal contamination sensing they developed through research at CEBSM. This novel sensor is ideal for bath-life extension (reducing chemical usage); it now has found other applications in various aspects of contamination control and dielectric characterization. The firm has two employees

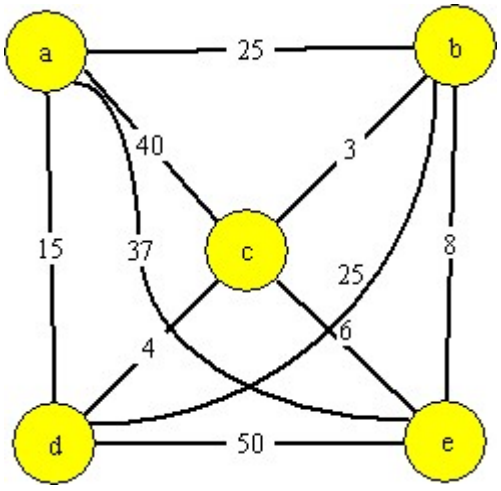
Praesagus: Founded in 1999 by Taber Smith and David White, ERC alums from MIT, this company commercialized some of the new CMP characterization and modeling technology researched in Professor Duane Boning's group. This has been an ERC-funded project since 1996. CMP is the fastest growing area and one of the largest segments of semiconductor manufacturing. In 2006, Praesagus was acquired by for $25.8M by Cadence Design Systems, a Silicon Valley provider of software and hardware, methodologies, and services to design and verify advanced semiconductors, consumer electronics, networking and telecommunications equipment, and computer systems.

INSTITUTE FOR COMPLEX ENGINEERED SYSTEMS (ICES) – Carnegie Mellon University (class of 1986-1997)

Founded originally as the Engineering Design Research Center (EDRC), this center aims to develop advanced design methodologies to drastically reduce the design-to-product cycle, and to build flexible, domain-independent design environments to integrate quantitative and qualitative methods for design optimization.

Product/Process Successes

Saving Money for the Traveling Salesman: Since its origination as the Engineering Design Research Center in 1986, the Institute for Complex Engineered Systems has fostered multidisciplinary engineering design research. The Center has embraced new technologies ranging from wearable computers to the modeling of organizations as information networks, involving both human and computer dynamics.



A simple illustration of a five-city traveling salesman problem.

An important example of the latter emerged during the Center's days as the EDRC with the work of Donald L. Miller and Joseph F. Pekny in bringing new efficiency to complex manufacturing processes. The researchers developed a groundbreaking technique for solving what's known in math circles as "the traveling salesman problem." In its essence, the problem poses the question of how to map the optimal route between a set number of cities. A salesman must visit each city only once, never retrace steps and return to the starting city. Easy to describe, it is grueling to solve: A visit to each of 15 cities can result in more than 43 billion possible routes.

The same questions arise in the batch-process scheduling faced by managers at manufacturing plants. Each city represents a job and the distance between a pair of cities represents the changeover cost to set up the batch process from one job to the next.

Miller, then an industrial resident from the chemical company DuPont, and Pekny, an EDRC graduate and now a Purdue University professor, in 1991 tackled an even more complex form of the question in looking at asymmetric routes, or processes where one choice is more expensive than another. It is pricier, for example, to paint a black car white than it is to paint a white car black.

Their algorithm solved the asymmetric optimality problem for up to 7000 cities in less than 20 minutes on a computer. That was 20 times the previous record of 350 cities. The technology proved so compelling that DuPont used it to revamp scheduling at 35 of its plants, and said it realized annual savings of $2.5 million for a number of years after implementing the changes. DuPont could realize such substantial savings because the volume of production of its chemical is often huge, making a small improvement in solution quality result in very large cost savings.

CENTER FOR ADVANCED ENGINEERING FIBERS AND FILMS (CAEFF) – Clemson University (class of 1998-2008)

The self-sustaining CAEFF provides an integrated research and education environment for the systems-oriented study of fibers and films, promoting the transformation from trial-and-error development to computer-based design of fibers and films.

Product/Process Successes

Modifying Substrates: CAEFF researchers have developed technology in the area of surface modification of polymeric and inorganic substrates. This technology uses a "primer" layer of poly glycidyl methacrylate (PGMA) to provide reactive groups on a surface that can subsequently be functionalized with other molecules, including biomolecules. Clemson University has licensed the technology to Invenca in the form of an exclusive license restricted to the field of liquid chromotography and to Aldrich Chemical in the form of a non-exclusive license restricted to the field of soft lithography, specifically PDMS stamps. Specialty & Custom Fibers has also licensed the surface-treatment technology for anti-fouling fibers for biological species.

Startup

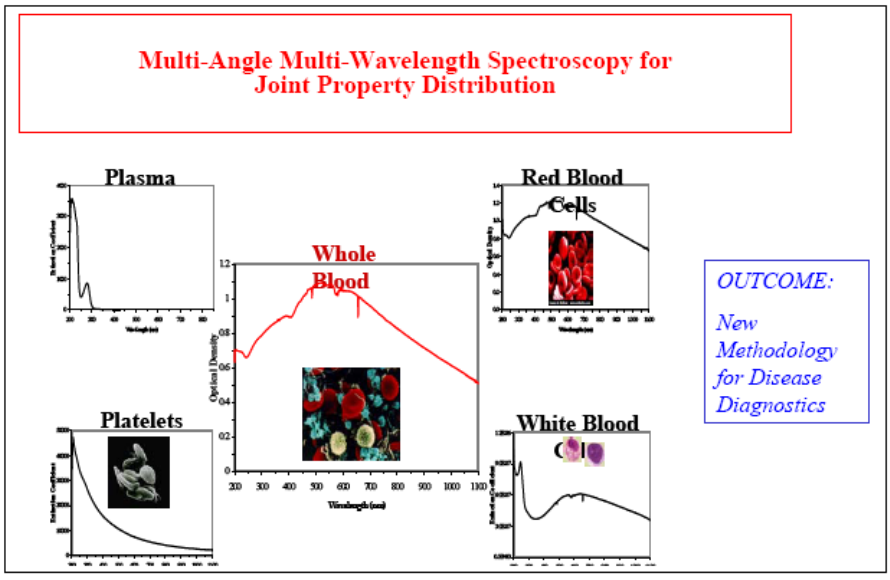
Specialty and Custom Fibers: Professors Ken Marcus, Philip Brown, and Igor Luzinov, all active research members of the CAEFF, founded a spinoff company to manufacture shaped (non-circular) fiber products that are designed to produce unique fluid transport properties and chemical behaviors, with particular applications in separation processes and biotechnology. They have also implemented new surface treatment strategies specific to targeted applications. The technology evolved from intellectual property owned by Clemson University Research Foundation. The firm became a legal entity in late February of 2005.

PARTICLE ENGINEERING RESEARCH CENTER (PERC) – University of Florida (class of 1995-2006)

The vision of this graduated ERC is to develop innovative particulate-based systems for next-generation processes and devices that sustain and improve the economic well-being of the nation and contribute to the quality of the environment and public health.

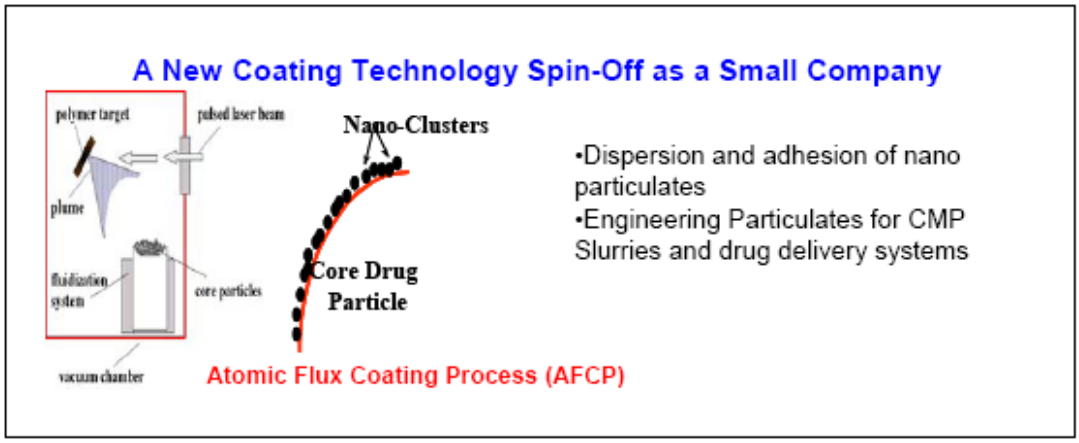
Product/Process Successes

Multiangle-Multiwavelength (MAMW) Detection System: With the support of the PERC, researchers developed a prototype instrument for acquiring and interpreting particle absorption and scattering measurements. The technology enables the interpretation of multiangle-multiwavelength spectral data. Novel algorithms produce estimates of the counts, size distribution, and chemical composition of particles. The instrument has been tested by several companies for various applications. Simultaneous determination of particulate properties such as size, shape, and charge, has been on the wish list of many sectors such as health, environment, chemical, and other processing industries. It can be estimated that the economic impact of implementing the sensor could be in tens if not hundreds of millions of dollars. Companies such as ICI, Xerox, Johnson and Johnson, and DuPont are in the process of implementing this technology in their operations and products.



Synthesis of Nanofunctionalized Particulates by the Atomic Flux Coating Process (AFCP): PERC researchers have synthesized a new class of particulate materials with specific functional characteristics. The particulates are synthesized by the attachment of nanometer-sized inorganic functional clusters onto the surface of core particles. The researchers have demonstrated that the synthesis of artificially structured, nano-functionalized particulate materials with unique optical, cathodoluminescent, superconducting, and electrical properties. Attaching atomic-to-nanosized inorganic, multi-elemental clusters onto the surface of the core particles can generate materials and products with significantly enhanced properties.

Such materials can be used for a wide range of existing and emerging products involving advanced ceramics, metals, and composites which span multiple industries such as aerospace, automobile manufacturing, machining, vacuum electronics, batteries, data storage, catalysis, and superconductors. The Center has applied this technology to develop coated drugs for slow release. Initial results, of testing the coated drug in rats, are extremely positive. It is expected that hundreds of millions of dollars will be saved in this pharmaceutical application alone.



Startups

Nanotherapeutics (nanotherapeutics.com): This company was formed in 1999 (originally as NanoCoat) to license the Center's atomic flux coating process technology. The CEO of the company is James Talton, a former graduate student in the ERC. A particular focus is on coating drug molecules with thin, porous films to allow the timed release of the drug. The company has several other proprietary drug delivery technologies for pharmaceuticals, both in clinical studies and ready for market. An injectable bone filler, for example, is marketed under the name Origin DBM.

In 2009, Nanotherapeutics was awarded a $30.9 million, 5-year contract from the National Institute of Allergy and Infectious Diseases, part of the National Institutes of Health, to develop an inhaled version of the injectable antiviral drug, cidofovir. The drug would provide non-invasive, post-exposure prophylaxis and treatment of the Category A bioterrorism agent smallpox. The company was previously awarded a $20 million contract in 2007 to develop an inhaled version of gentamicin for the post-exposure

prophylaxis and treatment of tularemia and plague, both also Category A bioterrorism agents.

Nanotherapeutics has 18 employees and annual sales of about $17 million, according to ReferenceUSA.

Sinmat (sinmat.com): The company was founded by Dr. Deepika Singh and Prof. Rajiv Singh in 2001 to commercialize materials technologies related to semiconductor manufacturing and advanced storage materials. Semiconductor manufacturers use chemical slurries to smooth out rough topographies in order to join hundreds of millions of transistors, in a complex process known as chemical-mechanical planarization (CMP). Sinmat has demonstrated success in developing a next-generation CMP slurry based on proprietary chemistries and their "nanosponge" and other innovative particle technologies.

In March 2009, Singh was invited to a White House press conference with President Barack Obama, who cited Sinmat's business as growing despite the economic recession because of its success in improving semiconductor production. The company in 2009 also won its fourth *R&D 100* Award, also known as the "Oscars of Innovation and Invention."

Sinmat reportedly has 16 employees and annual sales of nearly $1 million, according to ReferenceUSA.

NanoMedex Pharmaceuticals (nanomedex.com): This company was founded by a group of researchers to apply nanotechnology to biomedical problems. The company licensed several patents from the University of Florida and the PERC to develop a formulation that allows drugs that are soluble only in oil to be soluble in water, allowing them to be administered intravenously. The formulation uses components that encapsulate the active pharmaceutical ingredient into nano-size spheres so small they allow the drug to become randomly dispersed in water and act as if the drug has dissolved in the water. The first successful project is the formulation of nanoemulsions of Propofol, a commonly used sedative, which the company has trademarked as Microfol.

The company graduated from UF Progress Park, the spinoff incubator of the University of Florida, which retains an equity interest in NanoMedex. The founders were Dr. Donn Dennis, Dr. Nik Gravenstein, Mr. Ken Johnson, Dr. J.H. Modell, Dr. Timothy Morey, and Dr. D.O. Shah. The company has three employees and current annual sales of about $400,000, according to Dun & Bradstreet.

INSTITUTE FOR SYSTEMS RESEARCH (ISR) – University of Maryland at College Park (class of 1985, reestablished in 1994 through 1997)

Founded as the Systems Research Center, the self-sustaining ISR is developing fundamental knowledge and tools for the seamless integration of advanced technologies into heterogeneous systems. ISR initiatives employ the combined efforts of academia and industry to accelerate the synthesis of existing and new technologies into better systems and products.

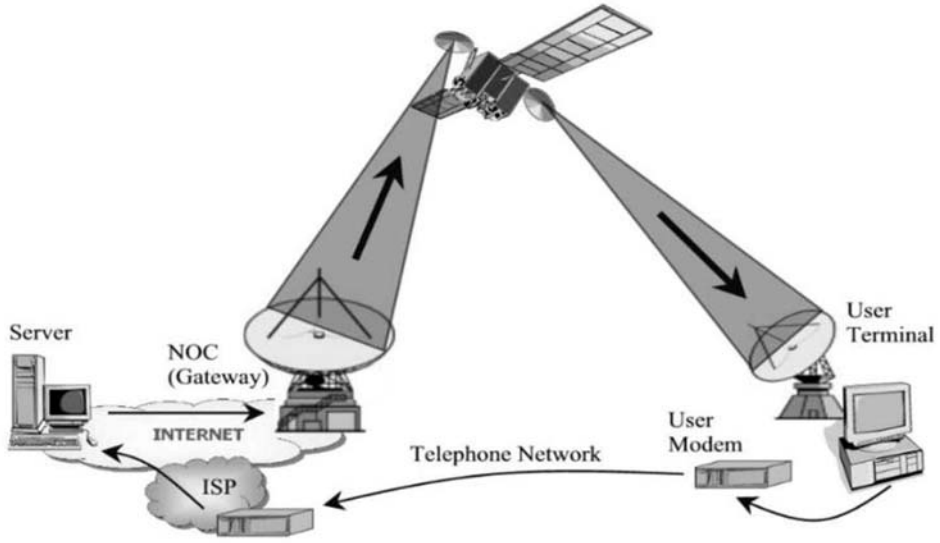
Product/Process Successes

Satellite-based Internet Access: Despite the rapid deployment of traditional cable and DSL broadband across the country and around the world, billions of people live beyond the reach of high-speed, wired Internet connections. That's created a multi-billion-dollar and growing market for satellite-based, two-way Internet connections conceived and designed by the Institute for Systems Research.

The ISR worked closely with Hughes Network Systems in developing the hardware and software necessary to multicast broadband data across satellites to terrestrial receivers at homes and offices. Hughes has marketed the resulting product under a variety of names, starting as DirecPC and now incorporated into its HughesNet offering, currently sold to nearly 500,000 subscribers in the U.S. With each customer paying rates that start at about $70 a month, the system is bringing recurring revenue of about $1 billion every year to Hughes alone. The ISR-developed technology also led to a worldwide industry of other companies delivering similar broadband services over satellites.

Providing Internet connections from space uses the same Direct Broadcast Satellite system that delivers one-way television to small, dish-shaped antennas on homes across America and around the globe. Delivering the Internet everywhere using the same satellite system posed daunting issues of latency, the inherent delays in sending radio signals across more than 100 miles of space.

The system developed at ISR exploited the asymmetric nature of Internet use, in which most computer users, especially those in a home environment, want to consume much more data than they will generate. The original DirectPC system downloaded broadband Internet over satellite links while depending on the public telephone networks for uploading data (primarily requests for Web pages). Even then, DirecPC required sophisticated connection-splitting approaches and new exploits of the Transmission Control Protocol (TCP) that is at the heart of Internet traffic, including TCP spoofing and selective acknowledgment dropping. The solution allowed larger transmission window sizes and avoided long-delay effects.



The original DirecPC system was a novel hybrid of satellite and telephone network links.

After launch of the initial system in the mid-1990s, the ISR worked closely with Hughes, then a division of General Motors and later spun off as an independent company, to develop later generations that introduced direct, two-way asymmetric communications between the satellites and ground-based customers. The work also significantly boosted speeds, with Hughes currently able to offer plans that reach speeds of 5 Mbps for downloads and 300 Kbps for uploads. In addition to utilizing the technology, Hughes hired many of the ISR students who have worked on the project through the years.

ERC FOR RECONFIGURABLE MANUFACTURING SYSTEMS (ERC/RMS) – University of Michigan (class of 1996-2007)

The graduated and self-sustaining ERC/RMS is pursuing a new manufacturing paradigm based on cost-effective, reconfigurable manufacturing systems whose components are reconfigurable machines and reconfigurable controllers, as well as methodologies for their systematic design and diagnostics.

Product/Process Successes

Performance Analysis for Manufacturing Systems: RMS technology is based on a systematic approach to the design and operation of reconfigurable manufacturing systems. A key element is giving a system-level planner the tools to evaluate the desired volume and mix, comparing productivity, part quality, convertibility, and scalability options. The planner then can perform automatic system balancing based on algorithms and statistics. One useful software package to perform these tasks is Performance Analysis for Manufacturing Systems, or PAMS.

Invented with the support of the ERC/RMS, the PAMS software package analyzes and optimizes manufacturing system performances. It has analysis modules for system throughput and work-in-process calculation and optimization. It can identify machine bottlenecks and calculates the optimal allocation of buffers for pull or push manufacturing systems.

A successful application of PAMS by the ERC/RMS came in 2007 at the Chrysler Indiana Transmission Plant (ITP), which was planning to add more pallets to reduce traffic blockage and streamline the whole Materials Handling System. ERC/RMS analysis using PAMS software instead recommended pulling out 15-18 pallets from the current closed-loop transmission machining line.

The plant implemented the recommendation, and Chrysler reported an observed increase of throughput around 5%. Considering the mass production scale of the assembly line, this single improvement on the transmission case machining line has saved Chrysler hundreds of thousands of dollars annually.

Similar applications in 2007 at the Ford Cleveland Engine Assembly line, and in 2008 at four production lines at the Chrysler Kokomo KTP plant, realized similar, if not greater, improvements in production. GM, meanwhile, imported the source codes of PAMS from the ERC and incorporated them into their own production throughput software.

Ford Engine Plant Process Changes: At an international conference hosted by the University of Michigan's ERC for Reconfigurable Manufacturing Systems (ERC/RMS), the keynote address was delivered by Roman Krygier, group vice president for Global Manufacturing and Quality at Ford Motor Company. During his talk, entitled "The Integration of Flexibility and Quality," Krygier outlined Ford Motor Company's powertrain manufacturing strategy, focusing on the ability to deliver high-quality products with a flexible and reconfigurable manufacturing system. This is being accomplished at Ford through the "communization" of equipment and processes—along with strong leadership from top management.

The ERC/RMS has had an impact on increasing the efficiency of the Ford Windsor Engine Plant, according to Krygier. "Working with the University of Michigan Engineering Research Center, we were able to apply the stream-of-variation methodologies. This research helped us to understand and confirm the linkage of features and characteristics. Based on U of M analysis results, we have changed our coordinate measuring machine gauging strategy to only measure representative features. This has led to a 65 percent reduction in measurements through the first three operations, with only negligible loss of data."

At each plant this technology results in a savings of two-thirds of the measurement machines and two-thirds of the measurement time, yielding savings of $1 million per plant in fixed cost plus $250,000 annually.

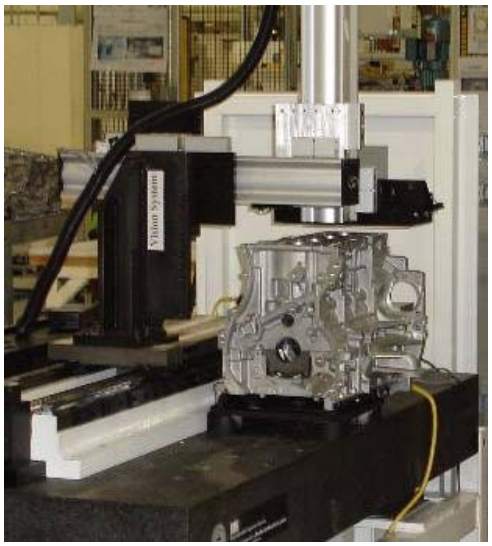
Reconfigurable Inspection Machines in Factories: A key challenge for the ERC/RMS and other industry-oriented academic engineering research centers is how to improve the transfer of new ideas and design concepts from the university environment to industry. One way to do it is to build full-size prototypes of machines that can demonstrate these concepts in an industrial environment—but ideally they should be portable for demonstration at many locations.

The ERC/RMS has developed a Portable Reconfigurable Inspection Machine (P-RIM) that facilitates technology transfer to ERC member companies. The P-RIM comprises a two-piece modular construction that is fully operational after a mere three-hour installation, set-up, and calibration procedure. It utilizes several new non-contact sensor technologies that can measure, within 20 seconds, features associated with a family of engine blocks. Because of this short measuring time, the P-RIM is capable of inspecting each part on a real-time basis directly on the machining line, thereby identifying machining problems immediately. Using RIM technology, the customer thus gets a better product and the manufacturer avoids scrap, which in turn increases overall system productivity.

The P-RIM can be reconfigured in a relatively short period of time in order to accommodate a set of measured features including surface flatness, profile, precise hole-location, and even surface porosity defects. Detecting pores on engine blocks at the line speed (20 seconds) is a huge problem in the automotive industry. Even when the pores are as small as 0.3 mm they may cause oil leaks in the engine. Currently, the automotive industry relies on manual visual inspection of porosity defects.

Detecting pores on the P-RIM was demonstrated successfully at the 2004 International Manufacturing Technology Show in Chicago; at Cummins in Columbus, Indiana; and at the 2005 NSF site visit at Morgan State University in Baltimore.

Currently the P-RIM is on the factory floor in a Chrysler plant in Michigan (see photo), checking porosity on engine blocks and working there like a real industrial machine.



The ERC/RMS Reconfigurable Inspection Machine is inspecting engine blocks on a Chrysler production line in Dundee, Michigan

In July 2006, this technology made a significant leap forward. General Motors utilized the knowledge base that was derived using the P-RIM in the development of an industrial system for in-line surface porosity inspection of engine blocks that was installed in a production line in Flint, Michigan (see following photo).

Cost savings associated with the use of the RIM system range from $500,000 to $2,000,000 annually at each manufacturing site. If the technology were to be implemented at all US powertrain plants, the potential annual savings would be $100 million.

An operator inspects the images of an engine block in which pores were detected and makes the intelligent decision whether the engine block is indeed defective.

ENERGY, SUSTAINABILITY, AND INFRASTRUCTURE

ADVANCED COMBUSTION ENGINEERING RESEARCH CENTER (ACERC) – Brigham Young University (class of 1986-1997)

The long-graduated but still self-sustaining ACERC's objectives are to (1) expand the fundamental knowledge of combustion in order to improve related technology and practices; (2) educate students at all levels about ways to increase the all-around efficiency of combustion, particularly in chambers fired by readily available, low-cost fuels; and (3) transfer developed combustion technology to industry to help solve crucial combustion problems.

Product/Process Successes

Computational Fluid Dynamics: With 85 percent of the world's energy coming from burning fossil fuels, ACERC's early research was aimed at making coal-burning plants cleaner and more efficient. Specifically, the center fostered the use of computational fluid dynamics (CFD) as a tool in this field, including improvements to the comprehensive 3-D entrained-flow coal combustion model (PCGC-3).

The current CFD market is dominated by software that arose from two companies, Fluent (now part of Ansys) and StarCD (now part of CD-adapco). Parts of ACERC codes are embodied in commercial software packages from both, which provide users with substantial cost savings in terms of lower emissions of NO, less carbon in the ash, and the ability to design new systems or refit old systems without extensive full-scale testing.

The benefits of CFD are largely aerodynamic. The software helps decide how to design burners, where to place overfire air registers, and whether or not to add additional fuel (i.e., reburning) or ammonia (i.e., selective non-catalytic reduction, or SNCR). It also helps plant operators evaluate coal blends, anticipate the impacts when they switch coals, and identify problem areas on the boiler walls due to corrosion, ash buildup, hot spots, etc. The value of these cost savings is difficult to quantify, since the software is now used worldwide in hundreds of plants and cost data are generally not available. However, it is enormous.

Startups

Combustion Resources (combustionresources.com): A 1995 spinout from the ACERC founded by the Center Director and partners, this company provides comprehensive consulting services in the field of fuels and combustion with expertise in analytical testing, computer modeling, and expert witnessing. Combustion Resources owns a 16,000 sq. ft. building in Provo, Utah. The company has reported annual sales as high as $7 million with 20 employees, according to Dun & Bradstreet. In 2009, CRI had sales of $2.7 million with 13 employees, according to ReferenceUSA.

Reaction Engineering International (reaction-eng.com): A 1990 spin-out from the ACERC located in Salt Lake City, UT, Reaction Engineering International is an R&D

consulting firm with an internationally recognized expertise in combustion and environmental solutions. Business areas include utility boilers & APCD, petrochemical furnaces, industrial furnaces, incinerators, rotary kilns, smelters, and stokers. The company has annual sales of $5.2 million with 25 employees, according to ReferenceUSA.

PACIFIC EARTHQUAKE ENGINEERING CENTER (PEER) – University of California at Berkeley (class of 1997-2007)

PEER operates programs aimed at cost-effective reduction of earthquake losses, with emphasis in: (1) understanding and mitigating the potential for collapse in older building construction so that major losses of life can be avoided; and (2) developing performance-based approaches for design of buildings and transportation and utility lifelines to provide life-safety protection for all construction, and protection of economic and functional objectives for essential facilities and operations.

Product/Process Successes

Predicting Losses Due to Earthquake: Beyond the toll in lives lost, earthquakes can cause billions of dollars worth of damage and incredibly costly problems for individual property owners and organizations. Having the ability to estimate those losses in advance can help in creating earthquake engineering policies, insurance products, safety plans, and improved structural design.

The Pacific Earthquake Engineering Research Center (PEER) has developed the Seismic Performance Assessment Tool, which combines seismic response data with building construction and occupancy data to compute expected losses.

The new tool enables engineers to convert complex multidimensional engineering data into decision variables, such as anticipated repair cost, that are easily understandable by lay decision makers. The software has been adopted as the main computational engine for a project funded by the Federal Emergency Management Agency entitled “Development of Next-Generation Performance-Based Seismic Design Procedures for New and Existing Buildings.”

Ground Motion Models Adopted by USGS: The U.S. Geological Survey (USGS) has adopted the results of the PEER Next Generation Attenuation (NGA) program, leading to extensive revision of the ground motion maps that serve as the basis for design of buildings, lifelines, and other facilities nationwide. This is the culmination of ten years of PEER research on the attenuation of earthquake ground motions with distance from the source earthquake. The research gathered data on earthquake sources, ground motion recordings, and site characteristics; it simulated earthquake recordings analytically where data gaps existed; and in a community effort it developed new ground motion models.

The USGS extensively reviewed the PEER NGA program and adopted the NGA models for developing the 2008 U.S. National Seismic Hazard Maps. According to the USGS, the “New NGA equations represent significant advances in fitting a larger standard dataset of ground motions and source and path parameters, and these equations should

replace the older equations for crustal earthquakes in the WUS." The new maps will significantly affect seismic design of most constructed facilities in the entire western U.S. (WUS).

Standards for Upgrading Concrete Buildings: The devastating Haiti earthquake of January 2010 dramatically illustrated the dangers that poorly constructed concrete buildings pose in an earthquake. PEER has developed a number of important innovations for the seismic assessment and upgrading of older hazardous reinforced-concrete building construction. In an early effort, PEER researchers developed the basic expressions for the ASCE Seismic Rehabilitation Standard (ASCE 41), defining the shear strength of concrete columns; these are the components of older concrete buildings that contribute most significantly to collapse risk. In a subsequent effort, first presented in a series of professional seminars, PEER presented several new seismic assessment procedures for older concrete buildings, covering a range of building components including columns, beam-column connections, slab-column connections, and shear walls. Not only were the seminars widely acclaimed, they prompted leading practicing professionals to call for a delay in the publication of the ASCE Seismic Rehabilitation Standard so these results could be incorporated. The new models lead to much more usable and cost-effective seismic retrofitting of hazardous buildings.

Building Seismic Analysis Standards: Earthquake ground motions pass from bedrock through the underlying soil and finally into a building. Along the way, interactions between the soil, foundation, and structure modify the ground motion—in some conditions increasing the motion that enters the building, in other conditions decreasing the motions. PEER innovations have led to two major changes in national standards for building seismic analysis, including seismic site amplification factors in the NEHRP (National Earthquake Hazard Reduction Program) Recommended Seismic Provisions, and kinematic interaction and damping provisions in the widely used FEMA 440 guidelines for simplified building analysis.

Earthquake Loss Estimation Procedures: PEER researchers worked with the California Earthquake Authority (CEA) to calibrate earthquake loss estimation procedures. First, PEER used seismic hazard maps to estimate the level of shaking anticipated throughout California. Analytical models of the housing stock, incorporating

representative damageability based on construction age and configuration, were then subjected to the ground motion estimates to determine anticipated damage. The results have been used by the CEA to calibrate home earthquake insurance rates throughout California.

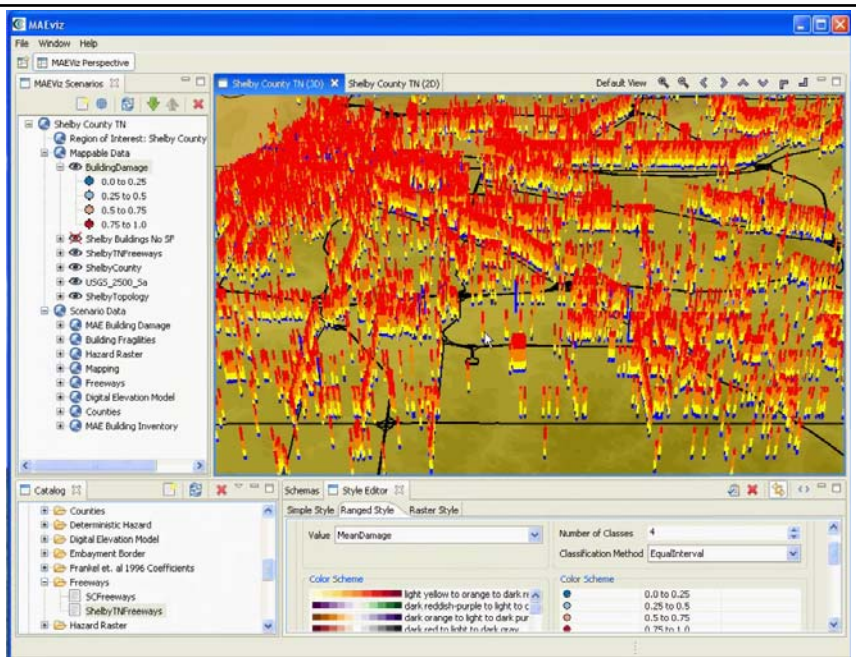
MID-AMERICA EARTHQUAKE (MAE) CENTER – University of Illinois at Urbana-Champaign (class of 1997-2007)

Research and educational programs of the MAE Center are directed at strategies and techniques that will reduce the potential loss from extreme seismic events as well as less-intense, but more probable, earthquakes. Research focuses on reducing economic losses and improving human safety across community-wide systems and national networks of the existing infrastructure, as well as on improving the understanding of seismic hazards in Mid-America.

Product/Process Successes

MAEviz Software: Collaboration between the MAE Center and the National Center for Supercomputing Application resulted in a pioneering package, MAEviz. MAEviz is an open source software project that allows users to estimate the impact of earthquakes, visualize losses, and undertaken decision analysis for mitigation options.

There are currently over 50 analyses, ranging from direct seismic impact assessment to the socio-economic implications. The software uses a Visual workflow system, providing user-friendly views into the inputs and outputs of analyses.



MAEviz showing potential building damage in Memphis, TN. Probabilities are shown as insignificant (blue), moderate (yellow), heavy (orange), and complete damage states (red).

MAEviz is being used by Memphis Light, Gas and Water; a major haulage company, Laclede Gas; CenterPoint Energy; the Municipality of Istanbul, Turkey; and on FEMA-DHS and IEMA projects, as well as in Pakistan and elsewhere in Turkey. Following the magnitude 5.2 Illinois earthquake of April 2008, usage of MAEviz increased markedly.

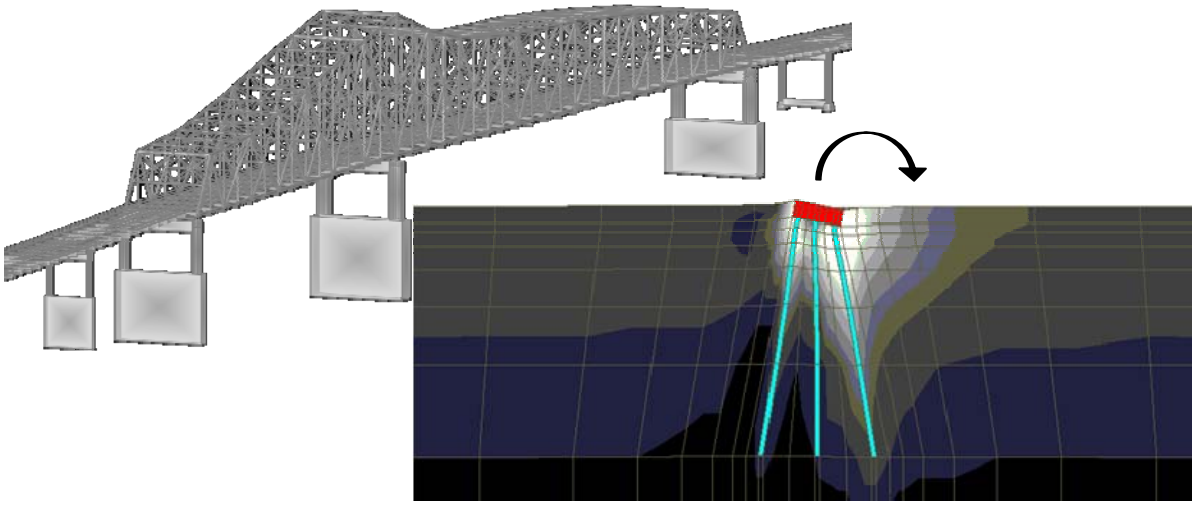
Earthquake Assessment and Retrofit of Critical Infrastructure: The MAE center used some of its core research tools as part of a stakeholder project, with Jacobs Civil, to assess the inelastic seismic response of the Caruthersville Bridge on interstate highway I-155 in Missouri. The study considered soil-structure interaction (SSI) and relative merits of various retrofitting schemes. Jacobs Civil is conducting this comprehensive project for the Missouri Department of Transportation.

The 59-span, 7100-feet bridge was built in the early 1970s across the Mississippi River between Missouri and Tennessee. The project site is about eight miles from the New Madrid fault. Refined three-dimensional, soil-structure-interaction analyses using state-of-the-art analytical tools and methodologies are underway to realistically assess the inelastic behavior of the foundation system. The SSI analysis is a key element in this study due to the massive and stiff foundation and the relatively soft deep soil. The length of the bridge and the diversity of its structural system emphasize the significance of the rigorous SSI analyses undertaken.

Several analytical platforms are employed in this study, including the MAE center analysis system ZEUS-NL, which is a product of the center’s Engineering Engines research thrust. Areas of vulnerability are identified by comparison of the capacities and demands obtained by analyzing inelastic pushover and response history. Use is made of strong-motion records from the MAE Center (products of the center's Hazard Definition thrust). Different retrofitting schemes are subsequently assessed to develop a range of feasible, efficient, and cost-effective retrofit alternatives. The state-of-the-art simulation methodologies enable bringing the most recent SSI research to support practice and improve safety of this major highway bridge.

Deepsoil Software for Understanding Ground Motion: The MAE Center continues to update software called Deepsoil that it developed for analysis of how soil moves during seismic activity. The Center conceived the program as a tool in analyzing deep soil deposits of the Mississippi Embayment.

Engineers use Deepsoil to qualitatively assess the influence of soil layers of varying stiffness and other characteristics on how ground moves during a seismic event. When earthquakes strike deep soil zones, the wave propagate through these soils for long distances. The computer program is particularly suited for analyzing the deep embayment deposits in the New Madrid Seismic Zone, an area in the southern and midwestern U.S.



3D simulation model of the Caruthersville bridge including refined soil and deep foundation modeling.

Now available as Version 3.7, the Deepsoil program has evolved into an educational and practical engineering tool with a friendly user interface. The interface contains many checks to help the user avoid mistakes commonly made when performing complex scientific analyses. Deepsoil also comes with built-in profiles of the material properties of various types of soil, enabling users to model columns of multiple layers of soil for theoretical or laboratory research.

Nearly 300 engineering researchers use Deepsoil in Missouri, Arkansas, Tennessee, California and Alaska. The program is also used as a teaching tool in courses offered at University of Illinois at Urbana-Champaign and other institutions.

Contributions to Building Design Codes: Center faculty's work on the vertical earthquake motion effect has been incorporated in two foreign-government seismic design codes, viz., the European seismic design code "Eurocode 8" and the Egyptian seismic design code. The same work was requested by two US-based regulations committees for inclusion in future guidance for design.

MCEER – The University at Buffalo (class of 1997-2007)

MCEER's mission is to discover, nurture, develop, promote, help implement, and in some cases pilot-test innovative measures and advanced and emerging technologies to reduce losses in future earthquakes in a cost-effective manner.

Product/Process Successes

Bracing Systems Go Into New Buildings. During the 1990s, MCEER researcher Michael Constantinou worked with a center industrial partner, Taylor Devices, to develop a toggle-brace concept for building reinforcement. The company then designed and built a toggle-brace system, donating one to MCEER for use in investigating the advantages of

mechanisms to leverage damping. Continuing research by Constantinou on how to make the concept more efficient then led to the development of the scissor-jack brace concept.

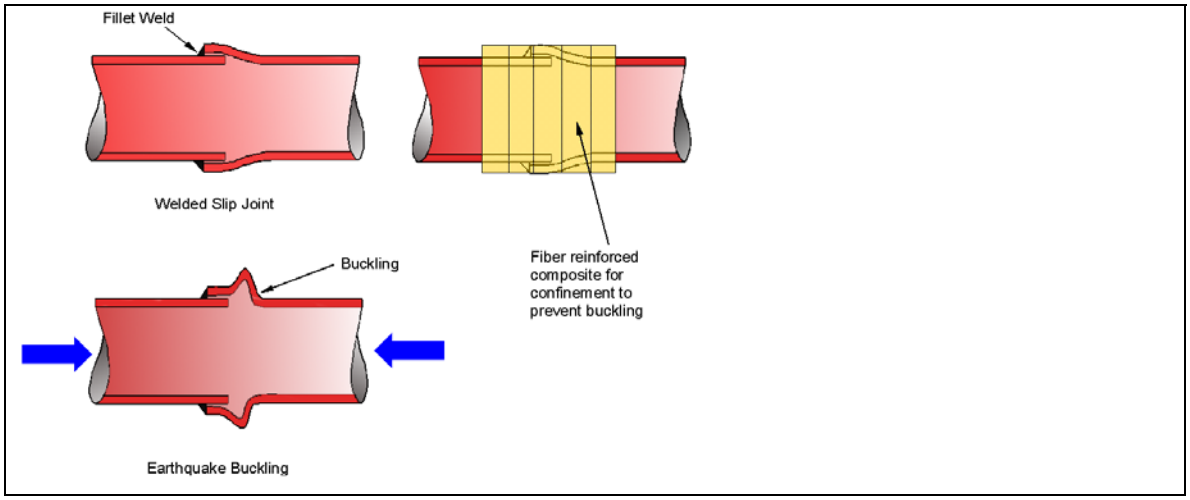
This latter concept is of great interest to practicing engineers due to the increased open-bay configuration it provides. Three 38-story buildings with toggle braces have been constructed (in Boston and San Francisco) only a few years after development of the concept. Considering that the scissor-jack brace is the natural successor to the toggle-brace, the future of the newer system is even more promising.

Fifty-two scissor-jack braces built by Taylor Devices were used in the Olympic House building on the island of Cyprus, completed in July 2006. This first implementation is particularly noteworthy given that the preparation and filing of national and international patents on the scissor-jack (in March 2001) prevented broader dissemination of research results prior to that time.

Over its ten years of association with MCEER, Taylor Devices reported that its sales of seismic products such as brace dampers grew from $4M to $8M.

3-story Olympic Committee building, Cyprus, employing the scissor-jack brace.

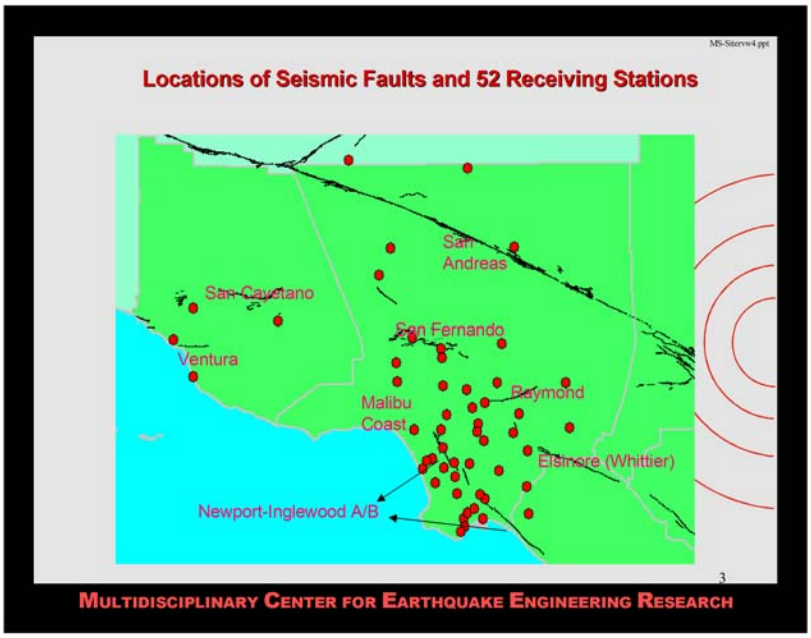
Strengthening Steel Pipelines: MCEER researchers developed a seismic strengthening system for critical water trunk lines using Fiber Reinforced Polymer (FRP) wrapping to



confine and strengthen welded slip joints against seismic compressive forces. Welded slip joints retrofitted with FRP technology restore pipelines to their full strength, as if they were straight sections without joints. This type of reinforcing can be used not only to retrofit existing welded slip joints, but also to strengthen new joints during fabrication in the field. The FRPs are now commercially available from several companies.

A New Breed of Lifelines: Lifeline systems—water and electric power, among others—comprise the infrastructure backbone of all communities. As we saw glaringly in Haiti, damage to these systems from earthquakes or other disasters can severely handicap rapid emergency response, the longer-term fundamental quality of life, and a region's economic foundations, with effects that can ripple throughout the economy. The impacts are even more pronounced in highly developed economies than in less-developed ones.

The resilience of lifeline systems is measured in terms of system robustness or strength, and the rapidity with which services are restored following a disaster. MCEER's solution is a new generation of lifeline systems that are more resilient to earthquakes and other disasters. With a specific focus on electric power transmission networks and water delivery systems, MCEER researchers have developed and deployed a Comprehensive Model for Integrated Electric Power Systems and a Comprehensive Model for Integrated Water Supply Systems based on the nation's largest metropolitan area, Los Angeles, California. Both models incorporate fragility and other data from experimental testing and analyses of the seismic behavior and functionality of various utility system components, and interdependencies between the two systems. The resulting decision-support systems have been deployed by the Los Angeles Department of Water and Power (LADWP), where they enhance system-wide planning and engineering.



Lifeline utility systems components in the Los Angeles, CA, region

FUTURE RENEWABLE ELECTRIC ENERGY DELIVERY AND MANAGEMENT (FREEDM) SYSTEMS CENTER – North Carolina State University (class of 2008)

The FREEDM Systems Center will partner with universities, industry, and national laboratories in 28 states and nine countries to develop technology to revolutionize the nation's power grid and speed renewable electric-energy technologies into every home and business. This center is one of the new "Generation-3" ERCs that are mandated to provide seed funding to start-ups for translational research to speed innovation.

Startups

Tec-Cel (tec-cel.com): Using technology developed at NCSU's Department of Textile Engineering, Tec-Cel is commercializing next-generation lithium-ion batteries by using a lithium alloy-carbon composite nanofiber anode. The technology has a theoretical storage capacity that is a 10-fold increase over current graphite anodes. Tec-Cel will use its lithium ion battery nanofiber technology to build standard battery cell building-blocks that will be incorporated by the end system manufacturer into battery packs for laptop computers, hybrid electric vehicles, wireless smart phones, power tools, and other consumer electronics.

The startup is being supported by the FREEDM ERC, including the center's small business incubation program. Tec-Cel has raised initial angel seed funding.

GaN Devices: Also being supported by the FREEDM ERC's incubation program, GaN Devices has raised initial angel funding for developing Gallium Nitride-based inverters. The technology represents a potential leap forward for highly efficient conversion of energy derived from solar cells.

MICRO/OPTOELECTRONICS, SENSING, AND INFORMATION TECHNOLOGY

CENTER FOR NEUROMORPHIC SYSTEMS ENGINEERING (CNSE) – California Institute of Technology (class of 1995-2006)

The mission of the graduated and self-sustaining CMSE is to develop the technology infrastructure for endowing machines with the senses of vision, hearing, touch, olfaction, and the ability to learn and adapt to their environment.

Startups and Product Successes

aVLSI: The CNSE has had a significant impact on several industries. Faculty and graduates of the CNSE have helped start 10 neuromorphic-related startup companies, a few of which (Digital Persona, Evolution Robotics, Foveon, Ondax, Cyrano Sciences) have become industry leaders in their field. The ERC estimates that the capital raised by these start-ups is in excess of $100M. Millions of consumers worldwide have benefited

from their products and technologies. Large corporations are being affected as well—products from Sony and Microsoft have been based on sensory systems developed by CNSE graduates and faculty working at Evolution Robotics and Digital Persona, respectively.

With VLSI pioneer Carver Mead as a driving force, the founding of the CNSE was in large part motivated by the idea that analog VSLI (aVLSI) chips could implement important components of sensory systems on a single low-power chip. A number of companies based on aVLSI (Synaptics, Foveon, Impinj, and Tanner Research), biometric (Digital Persona, Geometrix, IRIS, Real Moves), optics (Holoplex, Ondax), sensor (UMachines), and biomimetic (Cyrano Sciences, EndActive, and Evolution Robotics) technologies have either been launched as a result of CNSE research or benefited from CNSE relationships, research, and instruction.

IRIS—A Case Study: IRIS, the world leader in urinalysis systems, wanted to improve its product capabilities and reliability by shifting from its conventional chemical systems to a more robust technology that would depend on optical pattern recognition. The new technology developed in partnership with the CSNE ultimately spawned the most successful product line in the company's history.

SYSMEX, a Japanese instrument manufacturer, had introduced a urinalysis instrument adaptation of their blood-counter technology that is fully automated and requires no operator intervention. What IRIS needed was an instrument that could go a step further and automatically identify particles in urine and flag for human review only those specimens with characteristics set by the user. IRIS would then have the advantage of user review of the specimen images directly on its instrument, versus the SYSMEX instrument that would require a conventional manual review of every flagged specimen. The neural net technology developed by Professor Yaser Abu-Mostafa and his students, in the IRIS-sponsored CNSE research project, provided the needed particle identification.

The value of this technology proved enormous. In a large hospital, perhaps 25% of all specimens need to be reviewed. That means 50 specimens a day out of the 200 specimens that would be typical of a large hospital. Review on the IRIS instrument will on average take 1 minute compared to the manual process that can take up to 5 minutes, meaning a savings of 200 minutes per day per hospital. With a technician costing at least $30 per hour. The benefit per instrument is therefore $100 per day, or $30,000 per year assuming a 6-day workweek.

For society as a whole, the 357 IRIS installations nationwide with the automated instruments would realize annual savings of $10.7M. Outside the US, labor costs are typically less, but worldwide IRIS has about twice as many instruments installed. At half the U.S labor rate, an added $10.7M in savings amounts to a combined $21M per year worldwide.

DigitalPersona (digitalpersona.com): Founded by former CNSE students Vance Bjorn and Serge Belongie in 1996 when they were undergraduates, DigitalPersona developed "U. are U." fingerprint identification technology. Millions of users have benefited from the time savings of the biometric technology, notably buyers of a number of Microsoft keyboards and related products that incorporated DigitalPersona gear.

DigitalPersona products reduce “password fatigue” by making it more convenient to open password-protected pages while continuing to ensure privacy and security. The fingerprint reader is specifically designed to be intuitive and reliable. The fingerprint recognition technology allows people to log on to the PC, switch between users, and access favorite online sites at the touch of a finger.

In 2007, Analysts at Gartner Group estimate that it costs $180 per person per year in lost time to remember and enter passwords. Assuming DigitalPersona products last for three years, and with 500,000 known users in early 2007, the total cost savings to U.S. customers could exceed $130 million.

In late 2009. the company reported that its technology has been used by more than 95 million people worldwide. DigitalPersona employs about 90 people in Silicon Valley and has annual sales of about $20 million, according to Dun & Bradstreet.

Foveon (foveon.com, now part of Sigma Corp.) Established in 1997, Foveon developed the breakthrough X3 image sensor technology, a patented 3-layer image sensor architecture that provides a fundamentally better way of capturing color images. The technology was developed using standard CMOS semiconductor process steps and produced the world’s first commercially successful image sensor that did not require color filters to create a color image.

The Foveon sensor uses separate pixels to capture red, blue, and green light. The X3 sensor stacks the colored pixels in layers to allow light and color to be captured with three-dimensional feeling. The system is popular with professionals and photo enthusiasts, and is used across a line of cameras from Japanese lens-maker Sigma, which bought Foveon in late 2008.

Foveon continues to operate as a Silicon Valley subsidiary of Sigma, and has about 50 employees, according to Dun & Bradstreet.

Evolution Robotics (evolution.com): This company was started with the help of three CNSE faculty—Joel Burdick, Rodney Goodman, and Pietro Perona (the Director of CNSE)—and employs five CNSE PhDs. The company created the first commercially available object recognition system by vision. This system was available on the SONY Aibo, of which hundreds of thousands of units were sold. In 2009, Evolution won a federal contract from the U.S. Navy's Office of Naval Research valued at nearly $1 million for research on scaling visual recognition for maritime domain awareness

Evolution's Northstar technology is a low-cost, indoor localization solution that combines a small sensor, processor, and IR projector to provide accurate location information in real-time. In 2008, it was incorporated into the Rovio mobile webcam from WowWee, a device that can be controlled across the Internet as it roams a home or building. Northstar technology enables consumers to set waypoints that can automatically guide the robot.

Evolution has about 40 employees, according to Dun & Bradstreet.

Ondax (ondaxinc.com): Established in 2000, Ondax develops and manufactures all-optical advanced Dense Wavelength-Division Multiplexing (DWDM) components. Ondax is the world's leader in Volume Holographic Gratings, having built a manufacturing infrastructure for high-volume production. The Volume Holographic Grating has many advantages over thin film and fiber Bragg gratings. The narrow-band filtering capability in reflection mode (0.1 nm) over a large aperture (25 mm) is unique.

This unique filtering technology is used in high-power laser diodes wavelength stabilization, beam combining, astronomy multi-line filtering, and spectral imaging.

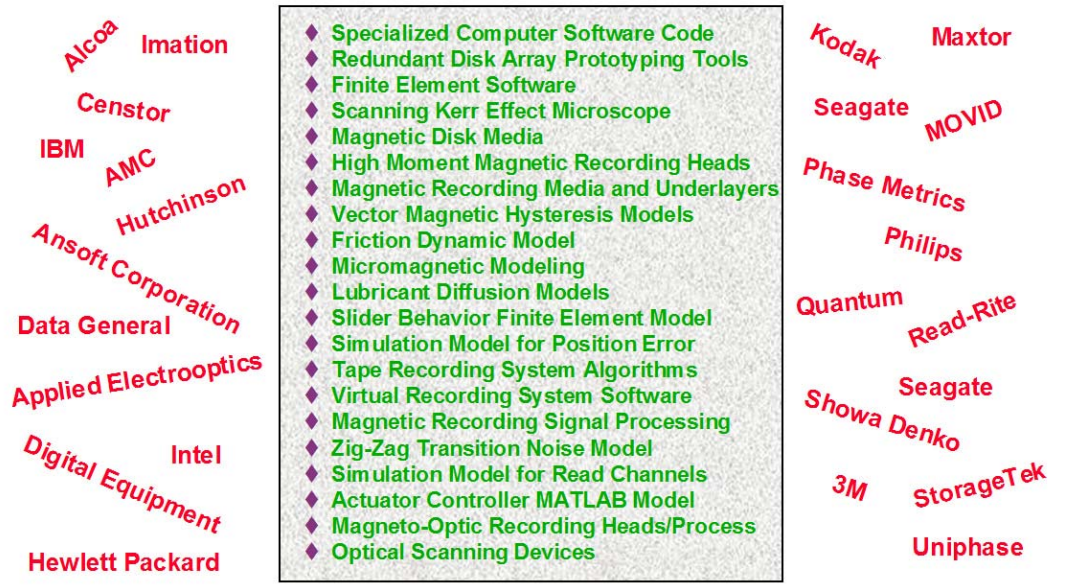
While a graduate student at CalTech, co-founder and CEO Christophe Moser developed devices and processes that are at the core of Ondax's technology. Ondax has about 10 employees and annual sales of about $2.4 million, according to ReferenceUSA.

DATA STORAGE SYSTEMS CENTER (DSSC) – Carnegie Mellon University (class of 1990-2001)

The mission of the graduated and self-sustaining DSSC is to pursue innovative cross-disciplinary research that will advance the state-of-the-art in magnetic and magneto-optic recording systems.

Product/Process Successes

Information Storage Industry Consortium (insic.org): In 1990, representatives of two of the industrial sponsors of the Data Storage Systems Center (DSSC) met with Center Director Mark Kryder to discuss the formation of an industrial consortium in the area of data storage technology. This discussion led to the formation in 1991 of the National Storage Industry Consortium (NSIC), a collective that sponsors over $135M in research through 11 collaborative programs. Known today as the Information Storage Industry Consortium (INSIC), it is the research consortium for the worldwide information storage industry. INSIC membership consists of nearly seventy corporations, universities, and government organizations with common interests in the field of digital information storage. Corporate membership includes major information storage product manufacturers and companies from the storage industry infrastructure.



Nickel-aluminum Underlayer in High-density Media: Probably the single most widely-recognized invention of the DSSC was the NiAl underlayer that enabled high-density media on glass substrates. This in turn was an enabling technology for making high-capacity drives for laptops and MP3 players, such as the Apple iPod. Because it is a widely deployed enabling technology, the commercial value of this invention is not possible to specify, but it is in the hundreds of billions of dollars worldwide.

DSSC/Seagate Connection: The founding Director of the DSSC, Mark Kryder, later became the Senior Vice President of Research and Chief Technology Officer for Seagate Corporation, a leading developer and manufacturer of computer memory storage media. Over the years he has received numerous awards for his achievements in this field. , Seagate was the winner of the *Wall Street Journal's* Technology Innovation Award 2006 in the "Technology Design" category for "Hard-disk recording technology that dramatically increases the amount of information that can be stored on a single disk." The research and development behind the hard drive designs that won the award were driven by Kryder's vision and underpinned by his work at the DSSC ERC throughout the 1990s.

DSSC Founding Director Mark Kryder

ERC FOR EXTREME ULTRAVIOLET SCIENCE AND TECHNOLOGY (ERC EUV) – Colorado State University (class of 2003)

The ERC EUV is partnering with the semiconductor industry in the development of Extreme Ultraviolet (wavelengths down to 13 nm) lithography, a transformational approach to the manufacture of future computer chips at the 32 nm node. With high-volume manufacturing set to start in 2011 and to extend for several chip generations, probably to 2020 and beyond, the EUV ERC is well positioned to have a significant impact on the $250B semiconductor industry.

Sematech-supported Micro-Exposure-Tool (MET) optics being installed at UC-Berkeley (an ERC EUV partner) for EUV photoresist and mask defect printability testing.

Product/Process Successes

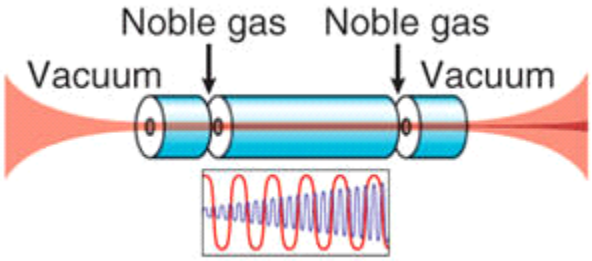
Extreme Ultraviolet on the Desktop: The value of extreme ultraviolet technology, with many applications including spectroscopy and materials analysis, is greatly enhanced by the ability to develop compact sources that can be used onsite by customers. That's at the core of the mission of the Extreme Ultraviolet Science and Technology ERC, which has seen its work lead to several products including the XUUS system sold by KMLabs, a member company of the center.

XUUS - eXtreme Ultraviolet Ultrafast Source

The XUUS (eXtreme Ultraviolet Ultrafast Source) is a tabletop system that guides the waves from an associated laser-

generation system. The XUUS system has been sold and installed in Germany and Israel during 2009 for applications in surface science and extreme nonlinear optics. The installations marked the first commercial sales of an ultrafast, coherent EUV source. Another installation is underway in Germany, and another is pending to the National Institutes of Standards and Technology.

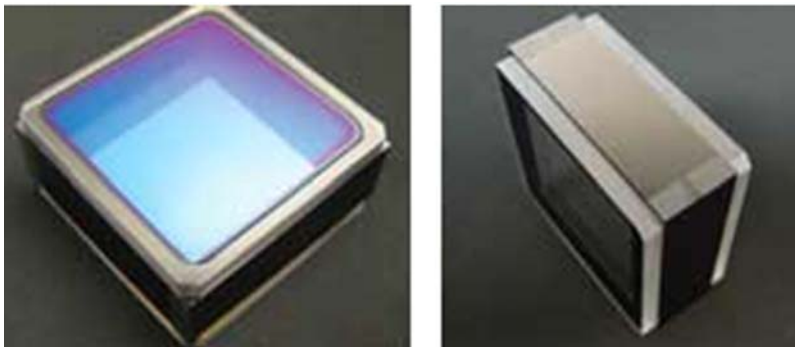
The system arose from work on high-harmonic generation (HHG) that was first demonstrated in 1998, in which light is generated at frequencies much greater than the original source. Advanced work on HHG is part of the EUV ERC research program and led to the engineering and upgrading of the XUUS waveguide technology.



High-harmonic generation occurs in a hollow, gas-filled waveguide.

In commercializing the technology, KMLabs is selling first-generation, high harmonic waveguide systems that produce light at a wavelength of 30 nm, already near the low end of extreme ultraviolet. Future products will optimize light at 13 nm and below.

YAG Laser Chip with Cladding on All Sides: Precision Photonics is now marketing a laser product developed in collaboration with the Center and advertised on their website. It consist of a laser crystal that is clad with absorbing material to suppress undesirable, amplified, spontaneous emission in a high gain amplifier. The product resulted from ERC EUV research conducted at Colorado State that is part of the effort to develop pump lasers for compact EUV lasers.



This high-power yttrium aluminum garnet (YAG or $Y_3Al_5O_{12}$) chip laser is a completely adhesive-free assembly comprised of several doped YAG components. Manufactured using Precision Photonics' patent-pending bonding process and advanced polishing techniques, this part required several iterative processing steps, thus highlighting the importance of robust, durable bonds and meticulous cleaning and handling techniques. Center researchers worked together with the member company from the raw material specifications through the final metrology in the collaborative development.

Startups

XUV Lasers: A spinoff of the EUV center, XUV Lasers is making available to all interested parties a desktop-size 46.9 nm laser that is based on fast discharge excitation of an argon-filled capillary channel. The compact EUV laser was successfully utilized to implement nanoscale imaging and patterning tools, and as a single-photon ionization source in mass spectrometry experiments. In 2008, the Institute of Physics of the Czech Academy of Sciences acquired one of these lasers for materials science experiments.

OPTOELECTRONIC COMPUTING SYSTEMS CENTER (OCS) – University of Colorado (class of 1987-1998)

The OCS pursued a cross-disciplinary research program in optoelectronic materials, devices, and architectures, exploiting the advantages of optoelectronics in computer interconnects, processing, and storage and display computer peripherals.

Startups

CDM Optics (cdm-optics.com, now part of OmniVision Technologies): CDM Optics was started in 1996 by founding OCS Center Director Tom Cathey, faculty member Edward Dowski, and industrial liaison officer "Merc" Mercure to commercialize the Wavefront Coding technology invented by Cathey and Dowski while at the OCS ERC. They formed the company to apply the patented technology, which substantially increases the performance of a camera system by increasing the depth of field and/or correcting optical aberrations of a photographic image, allowing everything in the field of view to be in focus without reducing the f-stop and thus the light level entering the camera. Wavefront coding is based on a pattern of small ridges etched into the lens. The image is then reconstructed using image processing. The advantages are that there are no moving parts (as there are in current autofocus systems) and the plastic lenses can be made inexpensively.

This startup was sold in mid-2005 to OmniVision Technologies (OVT), a company that makes CMOS detector arrays used in lenses for digital cameras, cells phones, security cameras, and the like. The sale allows CDM Optics, as a subsidiary of OVT, to acquire high-precision equipment and additional personnel to expand its impact in fields other than digital cameras. At the time of sale there were 18 CDM employees, including two in Japan. With OmniVision's purchase of a license from the university and the fact that the university had some equity in CDM Optics, the OCS gained some $800,000 in 2005 and another $200,000 in subsequent years, with a royalty flow of several tens of thousands of dollars per year going first to the OCS and later to the university.

Compared to images from traditional systems, CDM Optics' patented Wavefront Coding allows a wide-aperture system to deliver both light-gathering power and a very large depth of field.

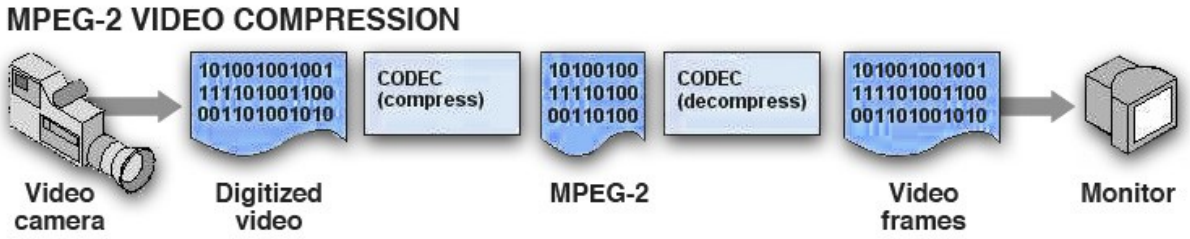
CENTER FOR TELECOMMUNICATIONS RESEARCH (CTR) – Columbia University (class of 1985-1996)

This center focused on all aspects of leading-edge telecommunications.

Product/Process Successes

Leadership in Digital Video: The Center for Telecommunications Research (CTR) participated in key developments that led to the international standard MPEG-2 for digital video. The technology is at the heart of modern digital video production and transmission. It is best known for its central role in Digital Video Discs, better known as DVDs, the plastic platters on which Hollywood has sold and rented billions of movies to consumers around the world.

Dr. Dimitris Anastassiou, a professor of Electrical Engineering at Columbia, is author of patents accepted as essential for the implementation of the MPEG-2 as well as the later standard of AVC/H.264, which are also used in digital television broadcasting and other means of delivering digital video. Dr. Anastassiou joined Columbia in 1983 and his work was supported by the CTR when it was established with NSF funding in 1985.



MPEG-2 is a compression codec that is used in Digital Video Broadcast and Digital Video Discs to transmit and store large video files.

Because of the work of Dr. Anastassiou and graduate student Feng M. Weng, and with the support of the CTR, Columbia University emerged as the only academic holder of a share of the patents used in the MPEG-2 standard. Columbia was one of more than a dozen holders of more than 40 patents that included consumer electronics giants Fujitsu, Mitsubishi Electric, Philips Electronics, and Sony. The MPEG-2 patent alone has brought more than $100 million in licensing income to Columbia University, and was a key factor in the university topping all other U.S. schools for licensing income during the late 1990s.

Dr. Anastassiou's work also helped lead to the AVC/H.264 standard that adds further efficiency to video storage and transmission. It is employed as a video compression codec by next-generation digital discs, both the Blu-ray Disc and in many types of digital video transmission, ranging from internet streaming to digital satellite television.

Beyond its support of research into the codecs that are central to the compression standards, the CTR also assumed a central role in the committee work that led to the MPEG-2 and later standards. The Center hosted numerous meetings of scientists working to develop the standards and participated in discussions that led to a groundbreaking licensing agreement among the more than a dozen corporate patent holders.

Analog Circuit Design: SWITCAP, a software simulator for mixed switched capacitors and circuits, was adopted by more than 170 companies involved in designing analog circuits. The software was developed at the CTR and licensed for the design of telecommunications, signal processing, and consumer products after its 1988 release.

A follow-on version, SWITCAP2, was also designed at the CTR and released in 1991. It also was widely adopted for mixed analog-digital circuit design by small and large companies that included Intel, Delco, Honeywell, Hays, Sierra, Samsung, Tritech, and Cardiac Pacemaker.

The simulators allowed industry teams to test circuit designs in a virtual environment, fostering more efficient designs and reducing production waste. Concurrent reductions in product development cycles were substantial for each company, and while those savings cannot be calculated, were enormous considering the widespread adoption of the circuit simulators.

MICROSYSTEMS PACKAGING RESEARCH CENTER (PRC) – Georgia Institute of Technology (class of 1995-2006)

This graduated and self-sustaining center is pursuing the development of low-cost, highly integrated electronic packages.

Return on Investment: According to a study prepared by SRI International for the Georgia Research Alliance, the taxpayers of Georgia benefit heavily from the state’s investment in the Microsystems Packaging Research Center (PRC) at the Georgia Institute of Technology. Between 1994 and 2004, the state of Georgia invested $32.5 million in the PRC. The SRI study shows that the direct benefit of these investments to the Georgia economy was nearly $192 million. Direct benefits include jobs created by

PRC and spin-off companies, license fees and royalty income from PRC inventions, sponsored research, consulting income to PRC staff and faculty, and the value of PRC workshops and short courses to Georgia firms.

In addition, the $192 million in direct benefits produced "ripple effects" on the Georgia economy in the form of indirect and induced benefits. These include purchases of goods and services by businesses that directly benefit from the PRC and by employees whose earnings come from PRC-related activities. The indirect benefits totaled an additional $159 million over ten years.

Thus, SRI estimates that the total quantifiable contribution of the PRC to the Georgia economy over 10 years was $351 million, more than a 10-to-1 return on the state's investment. The report is available online at:
http://www.sri.com/policy/csted/reports/sandt/documents/EconomicImpactonGeorgia2004.pdf

Product/Process Successes

System-on-a-Package: More than 160 companies have taken parts of the System-on-a-Package (SOP) technology pioneered by the PRC at Georgia Tech and applied them to their automotive, computer, consumer, military, and wireless applications. The PRC has also built a number of test vehicles for different companies focused on integrating different combinations of analog, digital, RF, optical, and sensor components in a single package.

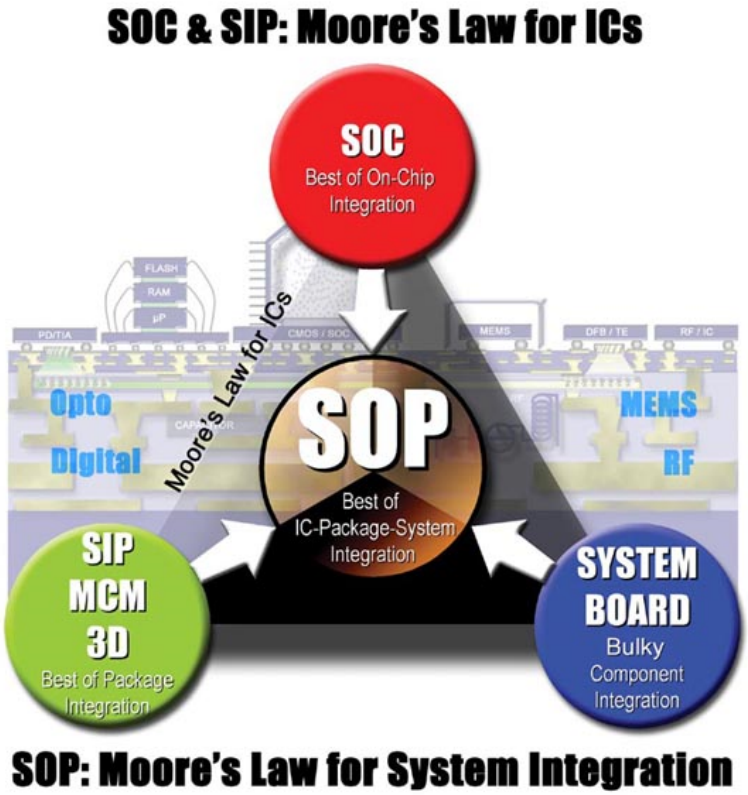
SOP is an emerging system technology that goes beyond System-On-a-Chip (SOC) and System-In-a-Package (SIP) and forms the basis of all emerging digital convergent electronic and bio-electronic systems. Unlike SOC, which integrates and miniaturizes 10% of a system, SOP miniaturizes the entire system. It does this by package integration with embedded components at micro-scale in the short term and nanoscale in the long term.

Motorola, as one example, was one of the PRC's founding industrial partners and used parts of SOP technology in two models of its GSM/General Packet Radio Service quad-band cellphones to gain about a 40 percent reduction in board area. The module contains all the critical cellphone functions: RF processing, base-band signal processing, power management, and audio and memory sections. Not only does the module free up space for new features; it is also the base around which new cellphones with different shapes and features (camera or Bluetooth, for instance) can be rapidly designed. Motorola calls its package a system-on-module (SOM), for which it developed its own custom embedded-capacitor technology. It reports it has shipped tens of millions of SOM-based phones as of 2009.

The SOP concept requires a "holistic" approach to design and manufacturing of systems—with integrated circuits, packages, system boards, and systems all designed and developed for fabrication at the same time. This spurred a major change in the prevailing manufacturing model, in which all these complements are designed and built separately and then assembled together. A number of different manufacturing techniques for SOPs

have emerged, including an SOP-like package with thin-film deposition on silicon wafers by Philips; organic boards by Shinko, Ibiden, and Matsushita; and ceramic boards by Murata and TDK. Companies that have adopted SOP as their strategy include IBM, Intel, Samsung, Sony, Panasonic, TI, Motorola, and Amkor.

The PRC believes that the market for multifunctional products and the advantages of designing chips and system packages concurrently are so compelling that companies throughout most industries involving microelectronics will soon be driven by the market to design and fabricate everything together.



SOP integrates the best of package integration, chip integration, and component integration into a single package system.

Startups

Quellan (quellan.com, now part of Intersil Corp.): Established in 2001, Quellan designed and marketed analog integrated circuits that dramatically enhance the performance of system interconnects and radio frequency receivers. Quellan chips are based on technology originally developed at the PRC by faculty member Joy Laskar and are embedded in connectors, receiver modules, and handheld mobile devices to improve speed, density, and reception quality. The company's patented Collaborative Signal Processing products perform adaptive noise cancellation and equalization with an entirely analog signal path for ultra low power. Quellan serves a broad range of applications in the computing, storage, consumer, and wireless markets.

Quellan raised $25M venture capital and had about 50 employees when it was acquired in 2009 by Intersil, a global designer and manufacturer of high-performance analog and mixed-signal semiconductors. Intersil announced the acquisition in October 2009, saying "Quellan's signal integrity products improve the reach and power efficiency of high-speed interconnections within data centers." The sale price has not been publicly disclosed.

Anadigics (anadigics.com, formerly RF Solutions)**:** RF Solutions was started in 1998 by PRC students Sangwoo Han, Anh-Vu Pham, David Cresci, and Carl Chun along with PRC faculty member Joy Laskar to provide integrated circuit and package design services for wireless communications markets. The company's products and 16 employees were acquired by Anadigics in 2003.

The Advanced Technology Development Center incubator program at Georgia Tech had helped RF Solutions obtain more than $14M in venture capital to produce integrated circuit chip sets and packaging modules for the wireless local area networks (WLAN) and fixed broadband wireless applications. After being acquired by Anadigics, the company was established as Anadigics' WLAN Center of Excellence. That Center has focused on power amplifier products for notebook and handheld applications. Anadigics WLAN power amplifiers became the best-selling in the world, with shipments totaling over 100 million units, and were responsible for approximately 25% of Anadigics revenue. Future development has centered on highly integrated RF front-end components such as single-chip power amplifiers, switches, and low-noise amplifiers (LNAs).

Engent (engentaat.com): This venture was started in 2001 by PRC faculty member Daniel F. Baldwin and several PRC students along with staff from Siemens' Advanced Assembly Technology Center. The original venture was founded under Siemens Electronics Assembly Systems to provide Siemens customers with process technology solutions complimenting the equipment platform. Engent formed as a spin-off from Siemens in 2003. Engent provides next-generation electronics manufacturing and packaging services and advanced process technology. The company shortens product time to market while enabling manufacturing at high volumes.

Engent employs Advanced Electronics Packages, MEMS, and Optoelectronics technologies, building on the PRC's novel, low-cost flip-chip process technology that directly attaches semiconductor chips to printed circuit boards without costly and bulky intermediate packaging. It has 11,000 square feet of manufacturing space including class-10,000 cleanrooms, comprehensive failure analysis facilities, and reliability testing facilities. The company has 21 full-time and 4 to 8 part-time employees, typically adding 2 to 4 new employees each year. Providing services to more than 140 customers, the company has been profitable since its inception, with annual revenue growth rate ranging from 12% to 25%.

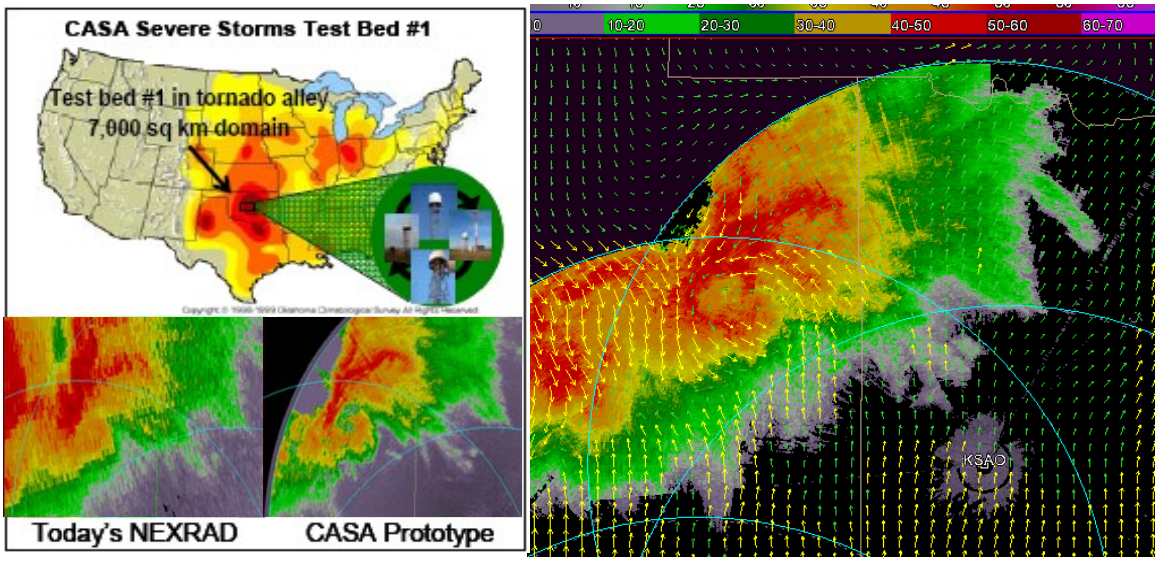
Harimatec: Through the participation of Japan-based Harima Chemicals, as a member in the PRC, and working closely with its Vice President, Mr. Henry (Hisao) Noguchi, the PRC has enabled the start-up of a Georgia-based subsidiary. Harimatec provides solder paste manufacturing, sales, and distribution for the U.S. In leveraging the relationship with the PRC and its infrastructure. Harimatec grew to employ 17 people, with $3.8M in sales in 2005.

ERC FOR THE COLLABORATIVE ADAPTIVE SENSING OF THE ATMOSPHERE (CASA) – University of Massachusetts Amherst (class of 2003)

Under rigorous and continuous peer review from the science and engineering community, CASA is investigating networks of small, low-cost radars that could be deployed on rooftops, communication towers, and other structures to fill gaps in today's NEXRAD radar coverage—especially the lowest regions of the atmosphere where severe weather forms.

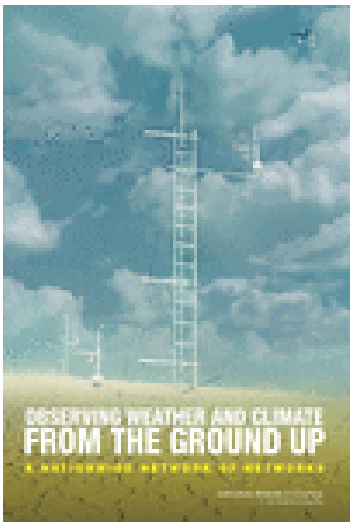
Product/Processes Successes

CASA Radar Network Allows Earlier Detection of Tornado: One of CASA's primary research goals for its experimental radar system is a clear demonstration of better detection of existing severe events than is possible with current technology. CASA has designed and deployed an end-to-end distributed-collaborative adaptive radar network in "Tornado Alley" in Oklahoma. CASA researchers are running real-time and simulated real-time tests of the system's value in conjunction with actual National Weather Service (NWS) forecasters. When a tornadic storm hit Anadarko, Oklahoma on May 13, 2009, a CASA forecaster in a real-time experiment was able to issue a "simulated warning" three minutes earlier than the NWS warning was issued during the actual storm. The current average lead time of the NWS for tornado warnings is 11 minutes, so a 3-minute improvement in warning time is significant. The NWS field emergency managers stated that this degree of improvement in lead time would give them a critical advantage in their ability to protect the public.



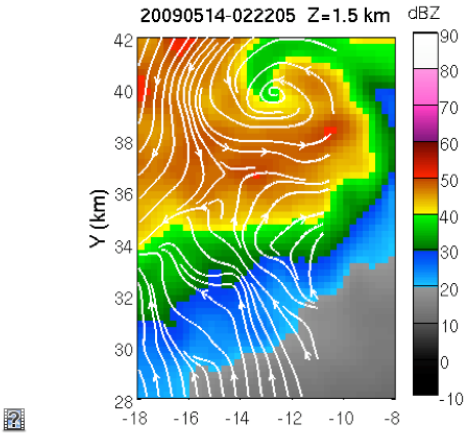
A CASA computer model showing rotating winds in an actual tornado enabled CASA researchers to issue a "mock" warning three minutes earlier than the NWS warning.

National Academies Report, *Network of Networks*: In the 2009 report, "Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks," the National Academy Press highlights the significant contributions to the future development of weather observation and prediction being made by the ERC for the Collaborative Adaptive Sensing of the Atmosphere (CASA). For one, CASA's technology can see weather close to the ground that presently goes undetected. The report also highlights the need for a national "network of networks." The report describes how networked sensors could respond to input from users and feedback from the environment, citing the CASA network as an example of how sensors can work together to measure precipitation and adapt to weather conditions. "The mode of operation is changed as the intelligence in the system responds to user needs, the prevailing weather, and the fault status of a neighboring sensor."



Radar Feasibility Study: Tornado and coastal storm-induced injuries, fatalities and economic losses in the states of Wyoming and Washington were the motivation for a congressionally funded report on the feasibility of new technologies to fill coverage gaps in today's national weather radar network. CASA researchers evaluated the weather information needs in the gap areas from a socioeconomic and meteorological point of view. They also analyzed the improvements in coverage that would be achieved by installing additional radars in Wyoming and Washington.

The study found that the gap coverage areas in Wyoming and Washington could benefit from additional low-level radar coverage from new technology, such as those under study by CASA, based on the climatology and the needs of weather-sensitive industries (such as transportation and mining), National Weather Service forecasters and emergency managers. For example, in the mountainous terrain of Wyoming networks of small radars overcome beam-blockage because they can be strategically placed between mountains. The study also recommended large radar deployment for long range coverage over the ocean to track and predict coastal storms on the western coast of Washington state. The next step is to conduct a cost benefit analysis. The report is at http://www.nws.noaa.gov/ost/radar/Radar_Report_Final_Corrected.pdf.



A tornado image captured by the CASA Engineering Research Center's ground-breaking radar networks shows unprecedented detail and clarity.

Startups

Dynamic Sensing Technologies (dynamicst.com): As CASA worked to develop and implement its first distributed, collaborative, adaptively scanning (DCAS) radar network in Oklahoma—the integrated project 1 (IP1) testbed—an undergraduate student from UMass-Amherst, Luko Krnan, established his own start-up firm. The firm, Dynamic Sensing Technologies, began operations in 2005. This company provides the research and operational radar communities with fast, high-quality engineering services and products. The firm has extensively supported CASA's system-level testbed in Oklahoma, including the fabrication of the IP1 data acquisition system, operational support for the prototype radar at UMass-Amherst, and the engineering for the four-node IP1 fabrication and deployment. Dynamic Sensing has contracts with a growing number of organizations, including CASA and NASA.

ERC FOR WIRELESS INTEGRATED MICROSYSTEMS (WIMS) – University of Michigan (class of 2000)

WIMS focuses on miniature low-cost integrated microsystems capable of measuring (or controlling) a variety of physical parameters, interpreting the data, and communicating with a host system over a bi-directional wireless link. As such, the Center addresses the intersection of microelectronics, wireless communications, and microelectromechanical systems (MEMS).

Startups

Sensicore: Started in November 2000 by Professor Richard Brown, a researcher at the ERC for Wireless Integrated Microsystems (WIMS), Sensicore has commercialized ERC sensor technology for water chemistry. Sensicore develops smart sensors and sensor networks that automate water testing, data collection, and analysis for both drinking and wastewater applications. The company's WaterNOW online data network helps users understand these data through unique visualization and comparison tools while organizing their information, process, and testing procedures. The company has developed a number of products including a disposable microsensor in 2003; a hand-held device, WaterPOINT, for point-source testing in 2005; and in 2006, WaterNOW. In 2005, Sensicore raised $12 million in Series C round funding. In April 2006, the company was recognized as one of the "Michigan 50 Companies to Watch" at the *Michigan Celebrates Small Business* event held in Lansing, Michigan. Sensicore was acquired by General Electric in 2008 and at the time had about 30 full-time employees.

Discera (discera.com): Founded in 2001 by Professor Clark Nguyen, a WIMS researcher, Discera is a world leader in CMOS MEMS Resonator Technology. The company's broad portfolio of PureSilicon resonators offers a significant breakthrough in technology that is being used to create the industry's most advanced and economical frequency control and RF circuits. In 2004, Discera introduced its award-winning proprietary PureSilicon

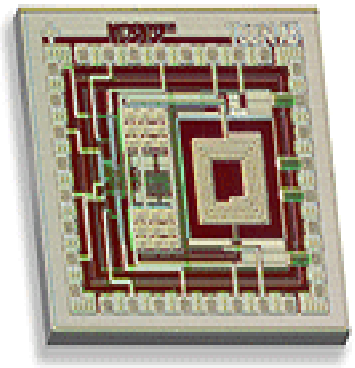
Resonator technology to provide an effective replacement solution to quartz crystal, ceramic, and other surface-acoustic-wave (SAW)-based frequency control and timing products.

Discera's products include not only its PureSilicon Resonator family but also crystal oscillator replacement products for industry-wide applications. These products uniquely address the miniaturization requirements of digital consumer products and other mobile applications. The company is selling its products worldwide.

In December 2006, Discera and M-RF Co., Ltd., a major distributor of microwave devices, components, and subsystems in Japan, announced a partnership to distribute Discera's CMOS MEMS resonator-based timing products. M-RF represents Discera and distributes its products to Japanese customers focusing on wireless communication markets. In January 2007, Vectron announced it was shipping Discera products to replace quartz crystal oscillators for high-volume applications. The worldwide timing market is $3.5B. Discera was featured on the cover of *EE Times* in the October 23, 2006 issue.

Mobius Microsystems (mobiusmicro.com): Founded in 2004 by Michael McCorquodale, while a student under Professor Richard Brown of the WIMS ERC, Mobius Microsystems is a leader in all-silicon clock generation technology. Leveraging broad design expertise in the RF and analog domains, Mobius develops clock generation products in standard CMOS processes. Mobius' products enable lower power consumption and lower total product cost through greater levels of circuit integration, improved performance, and faster time-to-market.

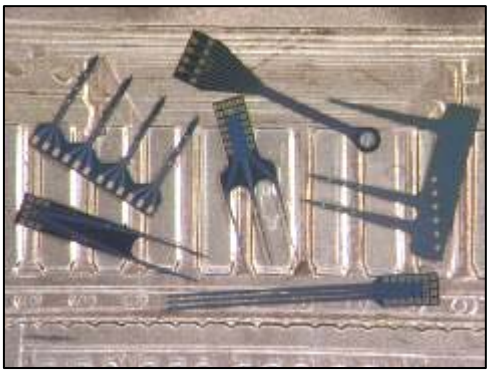
In May 2005 Mobius introduced the Copernicus Clock, a fully-integrated, high-accuracy, and low-jitter all-silicon clock that can be configured to generate multiple output frequencies from kHz to GHz with no external components. It is available as a hard macro for licensing and integration into product applications including microprocessors, microcontrollers, data communication controllers, SoCs, ASICs, and ASSPs.



Also in May 2005, at Michigan Celebrates Small Business, the state's premier awards ceremony for entrepreneurs and the supporters of small business, Mobius received an award for "Largest Job Creation by a High-Technology Company." The company has design centers in Detroit, MI, and Sunnyvale, CA. Its designs offer more accurate and cheaper alternatives to ceramic oscillators, which represent a $300M market in the US alone.

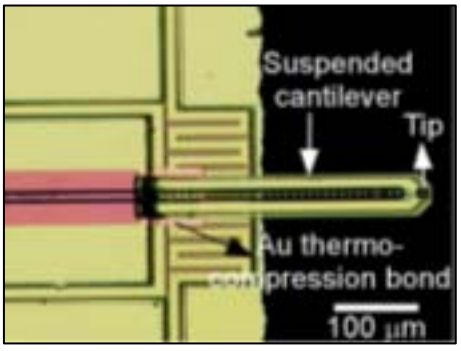
In 2009 the company had 11 employees and annual sales of $5.7 million. In January 2010, Mobius was bought by Integrated Device Technology, Inc. (IDT), a leading provider of mixed signal semiconductor solutions that enrich the digital media experience. "Mobius Microsystems' innovative technology extends IDT's clock leadership into high accuracy, crystal oscillator replacements, thereby doubling our served available market," the president and CEO of IDT said. The transaction is expected to expand IDT's worldwide timing market by some $700M.

NeuroNexus Technologies (neuronexustech.com): NeuroNexus (N2T) was formed in 2004 by Professor Daryl Kipke, a WIMS researcher, to commercialize neural probe technologies that were developed over nearly two decades of research in the College of Engineering at Michigan. N2T has licensed this platform technology from the university and is developing it into a focused franchise of neural probe systems for medical and scientific applications.



N2T's products are designed to provide microscale electrical and chemical interfaces with the brain that meet demanding application requirements in cost-effective configurations. N2T's unique technologies enable fabrication of research probes of any 2-dimensional shapes. NeuroNexus currently offers chronic probes of 16 and 32 electrical sites in one single probe. The company has received substantial State and SBIR support and has a development collaboration with Philips. It currently has 20-30 employees and is shipping product to the neuroscience community worldwide.

Picocal (picocal.com): Founded in 2005 by Professor Yogesh Gianchandani, a WIMS researcher, Picocal is a technology-based venture whose objective is to provide novel measurement solutions to its customers. The company's first product is a MEMS scanning thermal probe that enables users to quickly and clearly view and measure thermal properties at the nanoscale.



Picocal's products are designed to help researchers and manufacturers view critical characteristics that were not detected before. Picocal's high precision, non-destructive technique is based on a proprietary micromachined (MEMS) scanning thermal probe. The probe tip in the figure above has less than 100 nm diameter. Picocal's thermal probe is scanned across the sample and measurements are made at every location. Picocal also provides high-speed probes, frictional probes, microfabrication services, consultation, and contract R&D. Picocal recently received SBIR funding and is delivering product to customers, including the National Institute for Standards and Technology.

Nanobrick: Founded in 2006 by Professor Dean Aslam, a WIMS researcher, Nanobrick is marketing innovative educational learning modules and high-tech toys that help children explore and discover nanotechnology and related concepts. Nanobrick programs use materials developed through Aslam's association with WIMS' research and outreach programs. The company is developing its products in three phases: Phase I: CAMPS (Promotion of robotics, nanotechnology, and other science education programs); Phase II: Nano Tools for Kids (a suite of bricks that will form a suite of toys with interchangeable parts that can be used to build a diverse suite of devices including robots and toy nanosystems); and Phase III: Nano Sensors and Computing Devices (development of more advanced sensors, computing components, and nanosystems for marketing to industry).

ePack (memsepack.com): Founded in 2007 by Professor Khalil Najafi, Jay Mitchell, Sang-Woo Lee, and Joseph Giachino of WIMS, ePack is a MEMS packaging company and is implementing the packaging technology developed by the ERC in a variety of MEMS products. ePack provides wafer-level packages, vacuum encapsulation, and high performance hybrid packages that enable device manufacturers to produce cost-effective products for a wide range of applications.

CENTER FOR COMPUTATIONAL FIELD SIMULATION (CCFS) – Mississippi State University (class of 1990-2001)

The CCFS ERC embodies a synergistic combination of research efforts aimed at providing U.S. industry with the capability for computational simulation of large-scale, geometrically complex physical field problems for engineering design and application.

Product/Process Successes

A Partnership with Nissan: This graduated ERC has become the Institute for Computational Science and Engineering, a coalition of five independent centers that follow the ERC model of a cross-disciplinary team approach to strategically planned research. One of those centers is the Center for Advanced Vehicular Systems (CAVS). This Center has a research and development partnership with the Nissan Research Center in Japan based on Nissan's manufacturing investment in Mississippi, which was a direct outgrowth of the former NSF ERC's work in computational design and process simulation. The Center also coordinates an engineering extension facility near the Nissan plant at Canton, Mississippi.

The Institute for Computational Science and Engineering is a coalition of five independent centers at Mississippi State University, all stemming from the former ERC there.

The Center reports that the direct research expenditures of its component units from 1990 through 2009 have totaled $410 million. The overall economic impact of the collective ERC, including R&D, employment, and product sales is estimated at over $3B.

CENTER FOR ADVANCED ELECTRONIC MATERIALS PROCESSING – North Carolina State University (class of 1988-1999)

AEMP sought to develop technologies for high-quality, reliable wafer processing (cleaning, deposition, etching); to develop techniques for monitoring each process and characterizing the materials; and to use such information to automate and control the individual processes and to integrate the technologies into single-wafer processing module clusters.

Product/Process Successes

Single Wafer Processes for Semiconductor Manufacturing: At the Engineering Research Center for Advanced Electronic Materials Processing (AEMP), which graduated from the ERC program in 1999, research in *in situ*, single-wafer processing led to a number of processes which have been commercialized and are now part of mainstream semiconductor manufacturing at companies throughout the world—especially those member companies of SRC and SEMATECH who were among AEMP's industrial affiliates, including Intel, Texas Instruments, Motorola (now Freescale), AMD, and IBM.

One such process is the selective deposition of in-situ-doped junctions. But probably the most significant, and even revolutionary, commercialization of AEMP results is the use of high k gate dielectrics in semiconductor device manufacturing, starting in 2007. Two processes, both of which originated within AEMP, are key components of all the high k gate stacks being used by industry. One is the growth of ultra-thin (~0.5 nm) interfacial oxides having controlled amounts of nitrogen at the interface; the other is the use of chemical vapor deposition (CVD) processes using single-wafer processing to deposit, rather than to grow, a dielectric. The science and technology bases for these processes were developed in the ERC and transferred to the Center's industrial affiliates. The direct follow-on of the NSF ERC was the SRC/SEMATECH Research Center for Front End Processing, which elucidated the use of the Hafnium (Zirconium) families of high k dielectrics—all based on the single-wafer processing technologies learned in the ERC.

GORDON CENTER FOR SUBSURFACE SENSING AND IMAGING (Gordon-CenSSIS) – Northeastern University *(*class of 2000*)*

The Gordon-CenSSIS ERC seeks to revolutionize the ability to detect and image biomedical and environmental-civil objects or conditions that are underground, underwater, or embedded within cells or inside the human body.

Product/Process Successes

Arrayed Spectrometric High Efficiency Radiation Detector (ASHERD): Reliable, high-speed radiation detection has become an urgently needed element of homeland security. The ASHERD team was headed by signal processing and sensor fusion experts at the Gordon Center and instrument developers at Bubble Technology Industries. Together they developed the ASHERD unit, a flexible and cost-effective option for a next-generation portal monitor. ASHERD is an adaptive array of state-of-the-art spectrometric neutron and gamma ray detectors, chosen to maximize sensitivity and minimize false positives in accordance with national standards. The resulting system provides a unique and highly effective detection system for radiological and nuclear countermeasures. As team leader, the Gordon Center won a $4.5 million Department of Homeland Security (DHS) contract to develop the ASHERD prototype. The prototype was developed, tested against other similar systems, and was one of the winning prototype instruments.

With the ASHERD device developed, a new team led by Raytheon Company—a Gordon Center industrial partner—used it to compete for a proposed advanced spectroscopic portal (ASP) program at DHS. The Raytheon teams won a $400M DHS contract, one of three awarded by the government, to produce test ASP units for U.S. ports of entry. The first Raytheon ASP was installed in 2006 in the New York City Port Terminal in Staten Island, where DHS continues to evaluate it for cargo screening. As part of the cost of a nationwide detection system, DHS officials say the agency could spend as much as $3 billion on ASP equipment for the nation's ports.

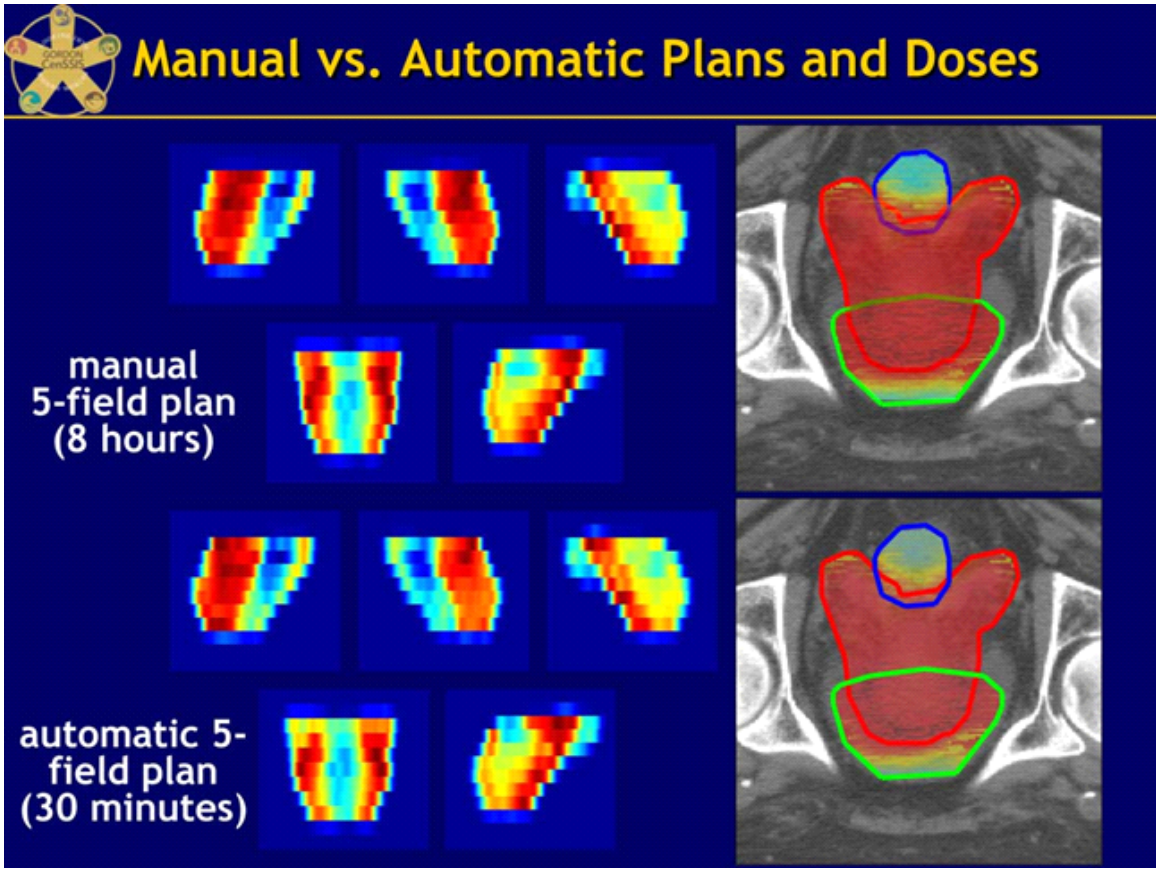
Embedded Roaming Sensors: Crumbling urban and transportation infrastructure has raised concerns about the nation's economic future, including an estimate from the American Society of Civil Engineering that it would take $1.6 trillion to address basic repairs. Even deciding where best to spend money is a daunting challenge, with inspections themselves often causing traffic jams and proving hazardous to drivers and workers both.

In 2009, CenSSIS was awarded a $9M, five-year Technology Innovation Program contract. The project, entitled "VOTERS" (Versatile Onboard Traffic Embedded Roaming Sensors), is focused on the pervasive assessment of civil infrastructure, including roads and bridges. The project will mount sensors on vehicles already on the road, such as taxis and buses, with transmitters that can autonomously send data to a central facility. The continuous reporting on road and bridge health can save cities and towns significant inspection costs. The sensors also can pinpoint problems for spot repairs before they become multi-week, lane-closing traffic nightmares.

Ming Wang and Sara Wadia-Fascetti, both professors of civil engineering at Northeastern, will co-direct the project. The researchers are confident that new technology will lead to commercial products that will prove important for efficiently identifying the weak points in the nation's infrastructure.

New Algorithm for Intensity-Modulated Radiation Therapy (IMRT): IMRT is a computer-controlled method of delivering radiation. It uses several beams from different angles that can precisely irradiate a target that has a complex 3-D shape, while simultaneously avoiding normal radiation-sensitive tissues.

A significant problem in 3-D IMRT systems is the amount of time and human intervention required to delineate the tumor and nearby normal structures on each pre-treatment scan. Usually a radiation oncologist takes 30 minutes to outline all of the structures of interest. Performing this operation each of the 30-40 times that a patient is treated is impractical and expensive. A second bottleneck is the determination of a multiple-field radiation plan that can meet the clinical dose constraints in all of the segmented organs. Depending on the site, an experienced radiation planner can spend hours adjusting IMRT objective function parameters to achieve a clinically acceptable plan. CenSSIS has developed a state-of-the-art segmentation algorithm that takes a computation time of only minutes and minimal manual intervention.



The IMRT algorithm has been used for prostate images at the Memorial Sloan-Kettering Cancer Center and for breast images at Massachusetts General Hospital (MGH). The

impact of this algorithm on the clinical setting is tremendous, freeing radiation oncologists from the burden of segmentation and dose constraints and allowing them to see more patients in the day, thereby increasing efficiency and reducing costs. Besides cutting IMRT prostate planning from several hours to about 10-30 minutes, the algorithm reduces the risk of exposing at-risk organs and normal tissues to unnecessary radiation.

Autonomous Underwater Vehicle (AUV): The AUV is a readily available and operationally simple research tool that allows rapid testing of docking methodologies and imaging algorithms. It performs change detection and quantification surveys in areas such as sidescan sonar, photo mosaicking, 3-D image reconstruction, and multi-sensor fusion.

The AUV is now being funded through its extensive user community but continues to provide support for the Center's basic work in imaging. Gordon-CenSSIS has also transitioned successfully to building multiple vehicles for outside users. The Center has delivered a highly cost-effective duplicate AUV to the Australian Center for Field Robotics, where it is being used to study coral reef systems at the Great Barrier Reef. Faculty and students in 2008 worked with the Woods Hole Oceanographic Institution (WHOI) to build an autonomous underwater vehicle (AUV) specifically designed for imaging coral reefs located 30-100 meters below the water surface. The AUV will map and monitor the deeper reefs of the US Caribbean. In 2009, advanced sensors such as a hyperspectral are being integrated into the AUV.

Tomosynthesis Acceleration: Tomosynthesis is a 3D mammography screening method developed by MGH and General Electric. One major bottleneck to its use is the long time (hours) needed to reconstruct the image from the raw x-ray data. To address this problem, Gordon-CenSSIS undertook a project on Tomosynthesis Acceleration on behalf of the MGH breast imaging group. The Center's researchers developed a parallelized version of the serial maximum-likelihood reconstruction algorithm, which reduced execution time of the algorithm from 2 hours to less than 5 minutes.

The parallelized code is now being used in clinical trials of the tomosynthesis device at MGH. This project is so important to MGH that the hospital has provided support for a Gordon-CenSSIS PhD to continue work on acceleration. This project has also collaborated with Mercury Computer, which has provided a high-performance computing unit for MGH to use in clinical trials. The potential potential impact is a much-improved imaging technology at significantly lower cost.

INTEGRATED MEDIA SYSTEMS CENTER (IMSC) – University of Southern California (class of 1996-2007)

The graduated IMSC seeks to advance multimedia—the integration of digital video, audio, text, animation and graphics—to dramatically transform the way we work, communicate, learn, teach, entertain and play.

Product/Process Successes

Hollywood Special Effects House Using ERC Software: University research on movie special effects? Naturally, if you're in Los Angeles! Hollywood special effects house

Rhythm & Hues has used “augmented reality” software from the University of Southern California’s Integrated Media Systems Center, a graduated ERC, to add computer-generated effects to movies more easily and many times faster. Named “Fastrack” by Rhythm & Hues, the software makes it easier to put computer-generated special effects into a film scene by finding points in the scene that can be tracked accurately over a series of frames when the objects or the camera move. IMSC’s software reduces the time it takes to track features in image sequences from minutes to just seconds per frame. The software also reduces the need for hand corrections. Rhythm and Hues has used the “Fastrack” software in a number of films, including "X-Men II", "Daredevil" and "Cat in the Hat."

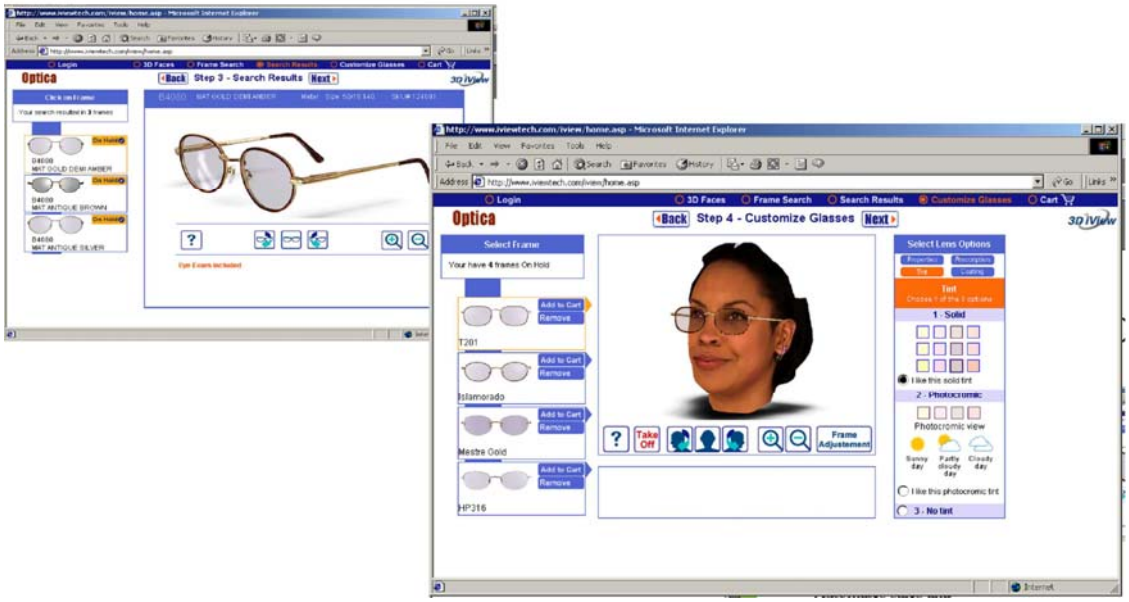
An Eyeglass “Virtual Try-on” System: A major element of the mission of all ERCs is to transfer center-developed technologies to their industrial partners for possible commercialization. An example of a success at the IMSC is its effort with 3D modeling technology. Center Partner Geometrix, of San Jose CA, licensed IMSC’s 3D face modeling technology and used it to create a high-speed 3D face capture solution, FaceVision™, and a “virtual try-on” solution for the retail optical market.

Geometrix developed a complete suite of automated 3D face capture and virtual try-on technologies that realistically simulate all the geometric and visual aspects of wearing eyeglasses. Armed with these technologies, Geometrix worked with Visionix of Israel to introduce 3D iView™, the first commercial 3D virtual try-on system for eyewear. 3D iView™ is available today and can be purchased worldwide through Visionix.

The 3DiView product captures a 3D facial view using six digital cameras in seconds. With this view clients can then virtually 'try-on' a variety of 3D frames from the extensive database until they find a pair that they like...on their face.

Hoya Corporation, the world’s second largest manufacturer of eyeglass lenses and the largest supplier to Lenscrafters in the U.S., adopted the 3D iView™ virtual try-on system, deploying it in Japan under the name “3D Best,” with planned implementation worldwide. The 3D iView™ system was further enhanced to automatically drive “build-to-order” prescription eyewear fabrication, and to provide accurate facial biometric measurements. Both the consumer and the optical shops benefit: the consumer enjoys more privacy and a larger selection of frames; the optical shop reduces inventory costs and streamlines the order process.

This was IMSC's first complete, "end-to-end" technology transfer and commercialization success**.**

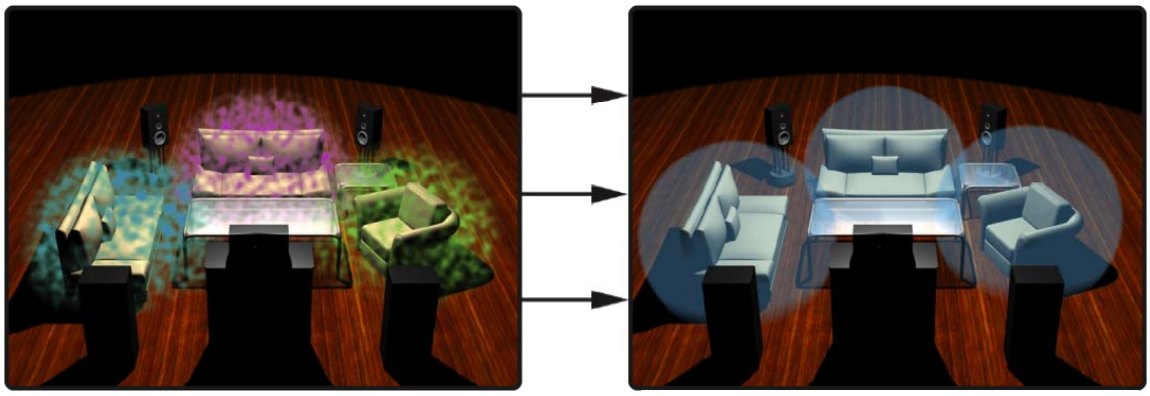


Product and screen shots of FaceVision™ 3D virtual eyewear try-on system based on IMSC-licensed 3D face modeling technology.

Correcting Distortions in the Listening Environment: MultEQ™ is the result of research in audio signal processing, acoustics, and psychoacoustics at the IMSC Immersive Audio Laboratory. The patent-pending technology was licensed to an ISMC spin-off company, Audyssey Laboratories that was formed in 2002. MultEQ automatically corrects frequency response distortions present in every acoustical environment. These distortions are caused by room acoustics and are very different from seat to seat. As a result, each listener's experience is not only degraded, but it is different from that of every other listener. MultEQ corrects the distortions at every position and makes the experience the same for everyone.

MultEQ allows the highest quality audio to be delivered even in the most demanding environments. Based on pattern recognition and the human hearing system, MultEQ is the only technology that automatically calibrates the entire audio system to ensure that every listener experiences high-quality audio regardless of where they sit within the listening area. MultEQ also automatically finds and sets the optimum crossover frequency for the subwoofer and satellite speakers, matches levels for each channel equally for every listener, and automatically sets the delay for each channel for optimum results. MultEQ was recognized in *Stereophile's Guide to Home Theater* as the "best technology demonstration" at the 2004 Consumer Electronics Show" in Las Vegas.

MultEQ is available as embedded software that runs on DSP chips that are currently in use in many home and car electronics products. Through Audyssey, it was licensed to several of the leading consumer electronics manufacturers in the US and Japan and has shipped in millions of systems.



Loudspeakers in a typical stereo or surround-sound system interact with surfaces to produce audible distortions at each listening position. MultEQ reduces the effects of the distortions, providing an enhanced, more uniform listening experience for everyone.

MacNeil-Lehrer Productions: The IMSC is courting a host of non-traditional industry partners from such diverse arenas as the financial services industry and direct marketing firms, to municipalities interested in developing tools to aid with large urban renewal projects, and television production companies looking to evaluate interactive applications for current and future programming. IMSC representatives have visited media organizations as diverse as the *New York Times* and Sesame Workshop—all interested in using IMSC interactive tools to enhance content offerings. One such example of a new and non-traditional IMSC partnership is that between IMSC and MacNeil-Lehrer Productions. Launched in March 2006, the unique, multi-year collaboration has seen IMSC helping develop tools that aid in interactive programming for MacNeil-Lehrer Productions television and Internet content, including the popular PBS NewsHour. IMSC's Serious Games Lab has taken the lead in this effort.

Geospatial Decision Making: The GeoDec team, led by Dr. Cyrus Shahabi at the IMSC, is undertaking a multidisciplinary project applying new techniques developed for databases, computer vision, computer graphics, and artificial intelligence. The tools enable a user to create a rapid and realistic simulation of any geographic area, whether virtual or real. Users can navigate the 3-D model, ask questions, and get information about the area in a user-friendly way. The most important feature is that the system seamlessly integrates many data sources, including satellite imagery, 3-D models, textures and video streams, road vector data, maps, point data, and temporal data for a specific geographic location. This allows the creation of accurate 3D models of areas such as the USC campus in a matter of hours.

A real-world application of the GeoDec system has been in the Grand Avenue Intervention, an ambitious $3 billion plan to revive downtown Los Angeles. The Annenberg Center for Communications funded the development of a GeoDec 3-D system that allows people to virtually explore the plans for building alongside the Grand Avenue park.

Google Earth and MSN Virtual Earth have also taken an active interest in the GeoDec project.

A 3-D model of downtown Los Angeles created with GeoDec.

Startups

Audyssey Laboratories (audyssey.com): Co-founded in 2002 by Prof. Chris Kyriakakis, IMSC Deputy Director, and former IMSC students Dr. Sunil Bharitkar and Phil Hilmes to commercialize a novel method of measuring and correcting the negative effects of room acoustics on sound from speakers.

In addition to the original technology, Audyssey has developed a number of innovative audio signal processing technologies for improving sound in home audio systems, cars, movie theaters, and portable music devices. The Audyssey brand has gained nearly 50 percent market share in home theater products, as a number of major consumer electronics companies have incorporated the company's technology into their products, including Denon, Marantz, Onkyo, NAD, Crestron, Alpine, and Sharp TV. The company is making deeper inroads into other markets with announcements in 2009 that the new Jaguar XJ uses Audyssey technology. In 2010 all Volvo cars will be using the company's products and IMAX Theaters has partnered with Audyssey to integrate the room correction technology in all their theaters starting next year.

Audyssey has raised four rounds of venture capital and employs 41 people.

Fetch Technologies (fetch.com): Founded by Profs. Craig Knoblock, Steve Minton, and Yigal Arens in 1999, Fetch Technologies has emerged as a leading provider of artificial intelligence-based Web Integration solutions. The Fetch Agent Platform provides fast and powerful integration of data from virtually any repository. Customers include Fortune 1000 companies, government agencies, search-and-retrieval companies, electronic publishers, and more.

The company was started based on technology sponsored in part at IMSC on information extraction from online semi-structured sources. Fetch's original product line, the Fetch Agent Platform, enables businesses to extract data from various websites and transform it into a usable format for applications. Fetch FootPrint is a platform of hosted solutions

designed for businesses that need to find and review important people data for making business decisions, such as candidate background screening, tenant screening, and security risk assessment, or for gathering profile information for the purpose of providing loans, insurance, and other services. Other products enable high-performance extractions of news sources and blogs.

From the initial 4 employees, the company grew to about 20 employees in 2007 and now has about 50 employees, according to Dun & Bradstreet.

Sentinel AVE LLC (sentinelave.com): Four partners who founded Sentinel in 2005 included two IMSC faculty: former IMSC director Ulrich Neumann and Suya You, a faculty member in Computer Science. Sentinel offers three products: Augmented Virtual Earth (AVE), a video fusion and visualization system useful for security and surveillance as well as general geo-spatial information visualization; 3D Modeling software for creating virtual models of terrain and buildings; and image recognition and retrieval software for identifying objects in images and rapidly searching for matches in large databases of images.

Customers of Sentinel, which Dun & Bradstreet reports has four employees, have included the U.S. Navy, a major US defense company, Chevron, Olympus, and Raytheon.

Geosemble Technologies (geosemble.com): Geosemble was co-founded in 2004 by Cyrus Shahabi and Craig Knoblock, both key investigators with IMSC since its inception. The company applies its Artificial Intelligence (AI) algorithms to a range of commercial and government user needs focused on automatically integrating information into satellite and aerial imagery and maps. Geosemble lists a dozen customers, including major federal agencies such as the Department of Homeland Security and U.S. Army, as well as local governments and private companies. Geosemble has 5 full-time employees, according to Dun & Bradstreet.

Phaethon Communications (now part of Teraxion): Founded by Prof. Alan Willner and IMSC graduate Bogdan Hoanca in 1999, Phaethon developed leading chromatic dispersion compensators which are used in optical networks to reduce the accumulated dispersion in optical pulses carrying digital information.

From the original two employees, the company grew to employ 75 in Fremont, CA. It raised $30 million in two series of funding from Mohr Davidow Ventures, the Photonics Fund, Goldman Sachs, and Cisco. The company and its IP were sold to Teraxion of Canada in 2003.

Eyematic Interfaces (now part of Vidiator Technology): The company was co-founded by Prof. Christoph von der Malsburg in 1997 based on unique software technology, co-sponsored at IMSC, that allowed computers to recognize human faces and emotional expressions in standard digital photos and digital video. Eyematic's breakthrough computer vision technology allowed real-time facial animation from just a standard video camera and PC. The company grew to offer a broad array of products before being acquired in 2005 by Vidiator Technology, which sells tools for the delivery of live and on-demand TV, radio, and music to mobile devices.

Digital Media Works: Founded in 2002 by Prof. Albert "Skip" Rizzo, DMW is developing applications of virtual environments to rehabilitation and training. It recently completed a major deliverable to an industry leader in the target market, and is waiting on the company evaluation of the results. DMW currently employs three people.

CENTER FOR POWER ELECTRONICS SYSTEMS (CPES) – Virginia Tech (class of 1998-2008)

This graduated and self-sustaining ERC has been pursuing an integrated systems approach to standardize power electronics components and packaging techniques in the form of highly Integrated Power Electronics Modules (IPEMs). The IPEM approach makes possible increased levels of integration in the components that comprise a power electronics system: devices, circuits, controls, sensors, and actuators.

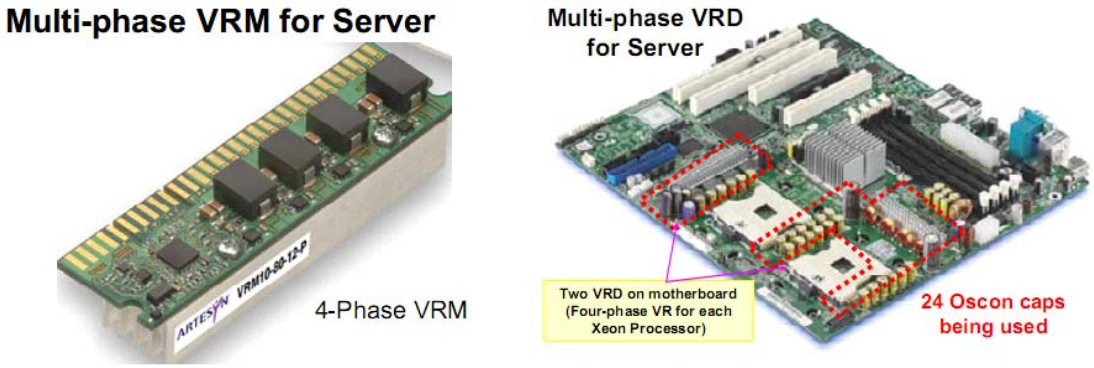
Product/Process Successes

Multiphase Voltage Regulator Module: Intel microprocessors operate at very low voltage and high current, and with ever-increasing speed, requiring a fast dynamic response to switch the microprocessor from sleep to power mode and vice versa. This operating mode is necessary to conserve energy, as well as to extend the operation time for any battery-operated equipment. The challenge for the voltage regulator module (VRM) is to provide tightly regulated output voltage with fast dynamic response in order to transfer energy as quickly as possible to the microprocessor. The first generation of VRM, developed for the Pentium II processor, was too slow to respond to the power demand of subsequent generations of microprocessors, which included the Pentium III and Pentium 4. As a result, a large number of capacitors had to be placed adjacent to the microprocessor in order to provide the required fast power transfer. This solution became costly and bulky.

Responding to Intel’s microprocessor challenges, CPES established a mini-consortium of companies with a keen interest in the development of VRMs for future generations of high-speed microprocessors. Since CPES at Virginia Tech first proposed the multiphase buck converter as a VRM for the Intel processors, this has become the standard practice in the entire industry.

Today, every computer containing Intel microprocessors uses the multiphase VRM approach developed at CPES. Besides all the computer manufacturers, other companies impacted by this CPES-developed technology include Texas Instruments, National Semiconductors, Analog Devices, Intersil, Semtech, STMicroelectronics, Linear Technology, Vishay Siliconix, Infineon, Maxim, International Rectifier, ON Semiconductor, Microsemi, Fairchild Semiconductor, Primarion, and Volterra.

This particular technology has developed into a multi-billion-dollar industry, and has given U.S. industry the leadership role in both technology and market position. It has also enabled new job creation and job retention in the U.S. Without this technology infusion from CPES, U.S. industry would have lost its market position in providing power management solutions to the new generation of microprocessors to overseas low-cost providers.

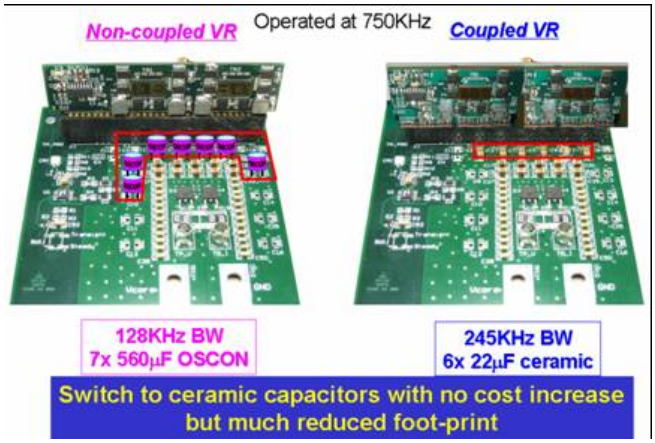


Current Sensing Technique for Multiphase Converters: One of the difficulties of implementing the multiphase buck converter that powers a computer's microprocessor is the issue of current-sharing among parallel modules. A common technique for ensuring current-sharing is to implement some form of current-sensing technique, usually by sensing the inductor current or switch current. However, the conventional implementation of current sensing does not lend itself to easy implementation in a control IC.

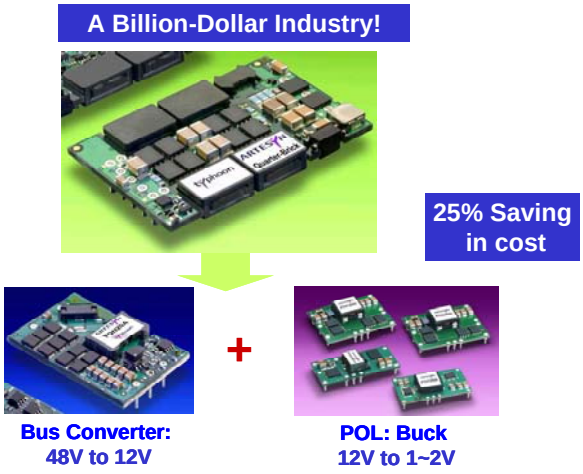
CPES has developed a patented technology, "A Novel Fast-Transient Response and Minimal-Sized Regulator Module with Novel Current Sensing and Current Sharing Technology" (U.S. Patent 6,414,469). This approach employs a simple R-C network to emulate the current going through the energy storage inductor, and is very easy to implement in a control IC. This technology has been adopted by such companies as Intersil, ADI, ON Semiconductor, Semtech, Texas Instruments, International Rectifier, Maxim, National Semiconductor, and Primarion.

Novel Multi-Phase Coupled-inductor and Current Sensing: Today, every microprocessor is powered by a multi-phase voltage regulator (VR). Each phase employs a sizeable energy storage inductor to perform the necessary power conversion. Generally, for such an application, large inductance is preferred for steady-state operation, so that the current ripples can be reduced. On the other hand, a smaller inductor is preferred for fast transients, such as from "sleep mode" to "wake-up mode" and vice versa. To satisfy this conflicting requirement, in principle, a nonlinear inductor would be preferred so that during the steady state the inductance value is large, while the transient value is small. However, there is no simple way of realizing such a nonlinear inductor.

In 1999, CPES proposed a coupled-inductor concept. When the inductors are coupled in a multi-phase buck converter, by virtue of the switching network, they behave like nonlinear inductors. The equivalent inductance is large for a steady state and small for a transient. This enables a multi-phase VR to deliver power to the microprocessor that is currently operating at GHz clock frequency. This proposed coupled-inductor concept enables much improved performance, resulting in reduced footprint and cost. The alternative solution to the coupled-inductor approach is to use a large number of decoupling capacitors to supply the transient power needed for the computer, which is cost-prohibitive. This CPES-developed concept has been adopted in industry practice.



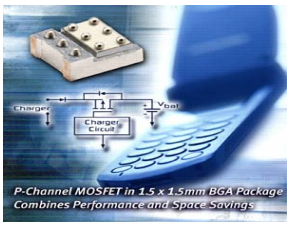
Eliminating the Use of Highly Customized DC-DC Converters: Following the multi-phase VRM approach, the infrastructure to support a multi-phase point-of-load converter was established, gaining the full support and endorsement of the computer, integrated circuit, semiconductor, and power supply industries. Not only has the technology been adopted to power every computer, it has also been adopted in many other point-of-load applications, such as the DC/DC converters for telecommunications, network products, and various forms of distributed power systems (DPS).



In the DPS architecture, CPES has proposed to replace the highly custom-designed DC/DC isolated converter with a novel two-stage approach, viz., a "bus converter." This serves as a "DC/DC transformer" used in the first stage to convert, for example, 48 V into an intermediate voltage—e.g., 12V—while the multiphase buck converter is adopted as a non-isolated point-of-load voltage regulator that converts 12V input to 1.2V output, or any other form of voltage required. By leveraging the infrastructure established for the multi-phase voltage regulator for microprocessor applications, this change has resulted in 15%-25% cost savings for the next generation of telecom and networking products.

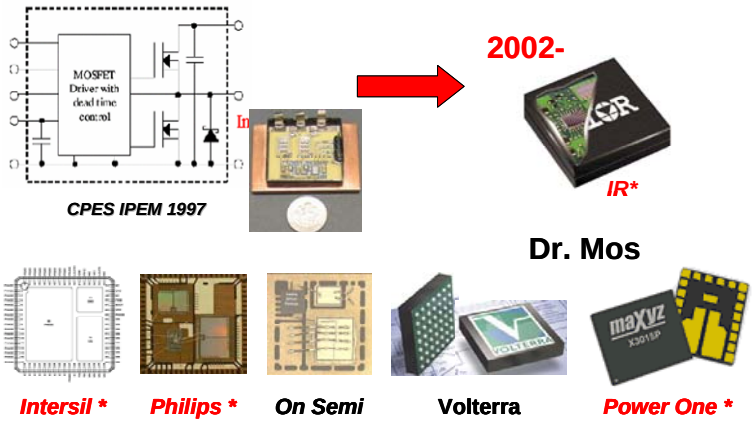
Wirebond-Free Packaging Techniques: The traditional power electronics packaging is achieved by connecting power semiconductor devices in the form of bare dies with aluminum bonding wires for functional interconnect. There is a significant amount of interconnect parasitics generated in this packaging approach. While this approach is generally acceptable for applications where the operating switching frequency is relatively low, it would be trouble-prone if one tried to increase the operating frequency into hundreds of kilohertz or higher. The packaging approach is also prone to failure due

to detachment of bonding wires and switching/conduction losses associated with interconnect parasitics.

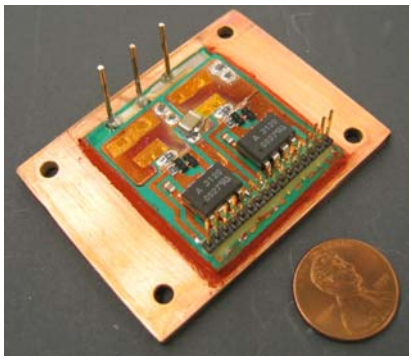


Beginning in 2001, CPES researchers have developed a number of wirebond-free packaging techniques for functional integration of power electronics modules, such as flip-chip-on-flex, dimple-array, and embedded power technologies—all of which are aimed at reducing the interconnect parasitics and improving the thermal management in the integrated package. In late 2002, several CPES industrial partners and others in the industry began to introduce products that use packaging techniques similar to what CPES had developed. They include Fairchild's bottomless and BGA packaging, Renesas's lead-free packaging, International Rectifier's FlipFet and DirectFET, Siliconix's PowerPAK, and STMicroelectronics's FLAT package. Features typically claimed in these products included reduced contact resistance for direct bonding (without bonding wires), reduced parasitic inductance, and improved thermal management, which are the same features CPES had reported.

Integrated Control ICs for Multiphase Solutions: CPES's research vision is to develop an integrated approach to power electronics systems via the Integrated Power Electronics Modules (IPEMs) to improve performance, reliability, and cost-effectiveness of power electronics products. Since 2002, a number of semiconductor companies, such as International Rectifier, Renesas, Philips, Power One, OnSemi, and Intersil—several of them CPES industrial partners—have introduced new products, referred to as "Dr.MOS," which are similar to the IPEM developed at CPES. These products are used to power the new generation of computers, telecommunications, and network equipment products.



Intelligent Power Modules for Motor Drives: For motor drive applications, CPES has developed a new class of integrated power electronics module (IPEM). Several CPES technology advances are being incorporated into the active IPEM design for motor



drives. Embedded power technology has been adopted to eliminate all wire bonds in favor of a planar interconnection scheme that minimizes dangerous voltage transients caused by unwanted parasitic inductances. In addition, the flat upper surface is valuable for mounting gate drives, sensors, and cooling components to extract extra heat from the top side of the module. Such advances contribute to reducing the module size while increasing its long-term robustness.

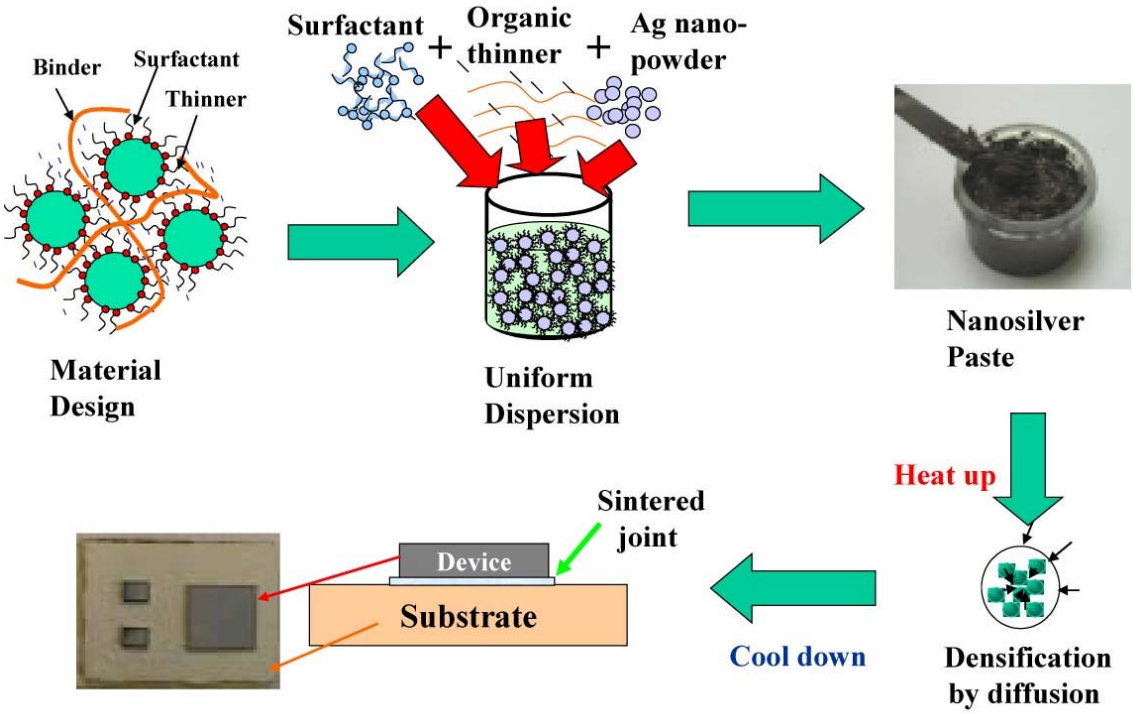
Embedded power phase-leg IPEM

CPES has developed methods to integrate current sensing into power conversion systems using intrinsic properties without the need for additional interconnections. Methods have been developed which use simple, compact, highly sensitive, yet inexpensive magnetic field detectors that can be easily embedded in power conversion interconnections. Most importantly, the methods developed enable designers to avoid major potential pitfalls and obtain results superior to the existing state-of-the-art in current sensing.

Key concepts embodied in the motor drive IPEM architectures developed by CPES are being adopted in new power module products produced by major power semiconductor manufacturers, including Fuji, International Rectifier, and Semikron. These features include active gate drives, current sensors, and phase-current regulators that are all key elements of the CPES motor drive IPEM architecture. Semikron has included the GMR-based point field detector approach conceived by CPES for integrated current sensing in its newly introduced, highly integrated automotive IPEMs.

Startup

NBE Technologies, LLC (nbetech.com): NBE is moving forward with the commercialization of a nanomaterial technology transferred from CPES's research effort. NBE's nanosilver paste product line under the trade name of nanoTach won a 2007 *R&D 100* award. NanoTach can significantly improve the thermal, electrical, and high-temperature performance and reliability of electronic systems. The product is being actively evaluated by major electronics manufacturers in North America, Europe, and Asia for applications in automotive electronics, telecommunications modules, and LED lighting products. NBE has successfully secured SBIR Phase I and Phase II funding from NSF and SBIR Phase I funding from DOE.



Process for production of NBE Technologies' nanosilver paste product, being commercialized as nanoTach.