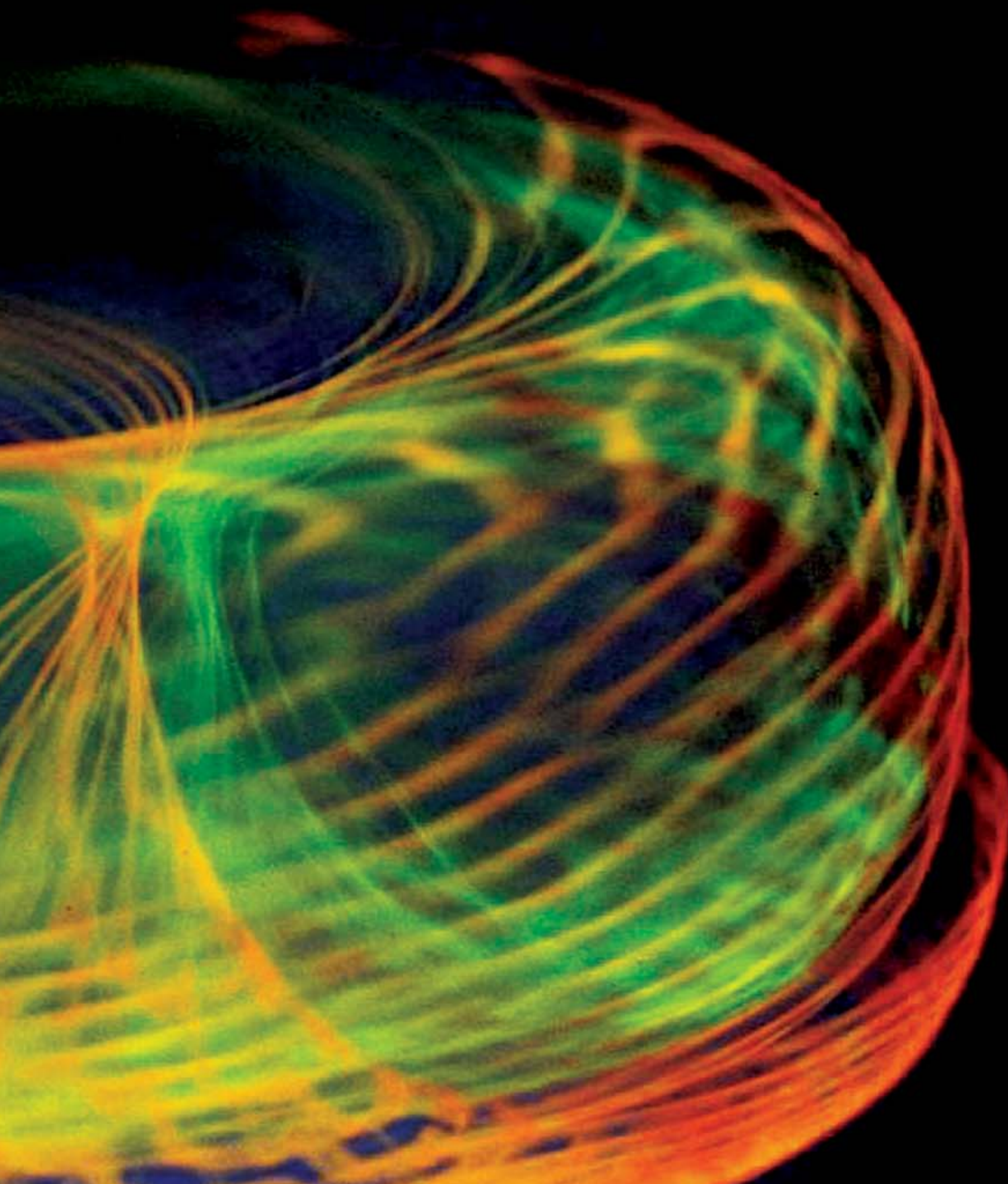
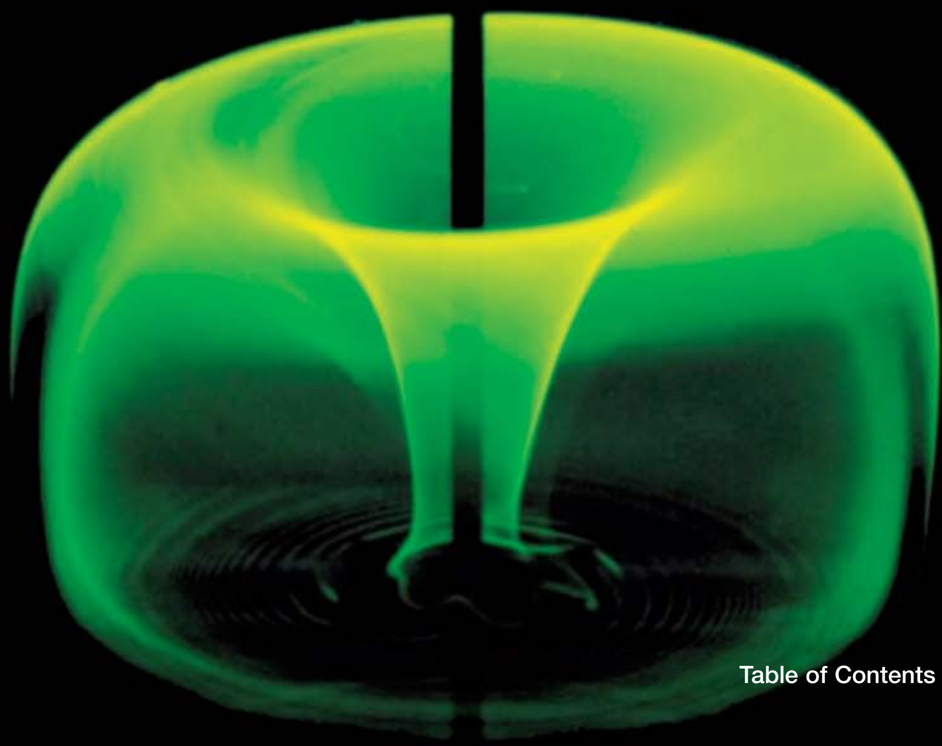
National Science Foundation

# Engineering Research Centers

## 2005–2006 Program Report



*Creating leading technologies, educating technology leaders.*



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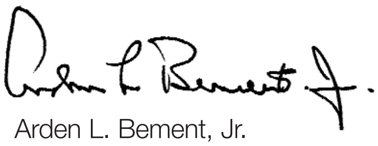
*Innovation through collaboration.*

For more than two decades now, the Engineering Research Centers have been among the brightest jewels in the crown of the National Science Foundation. Born at a time when the Nation's technological and manufacturing competitiveness was first coming under pressure from other countries around the world, the ERC Program aimed to reverse that trend by bringing U.S. academic engineering research, education, and practice back closer to its roots as the engine of innovation.

It did this through a focus on engineered systems, on strategic planning of research, on cross-disciplinary team research, and on collaborative partnership with industry researchers. In the early days, those emphases posed a considerable challenge to the traditional single-investigator culture in academia. But slowly, the ideas they embodied took hold and spread, eventually bringing an interdisciplinary, innovation-focused "cultural change" that can now be seen throughout our colleges of engineering and beyond.

Today the ERC program has grown to 22 active centers, including five new ones added in FY 2006–for a total of 43 successful ERCs established since 1985. In an atmosphere of tight budgets for research, this program is stronger than ever, a testament to its success and to the validity of its core principles. In a world going ever more global, with increasingly distributed strengths in engineering research and education, it continues to adapt and evolve to meet today's challenges. This 2005–2006 ERC Program Report is but the latest installment in a story that continues to unfold.



Arden L. Bement, Jr.
Director, National Science Foundation

# The ERC Story

**The Guiding Goal** - To enable transforming systems technologies and educate a globally competitive and diverse engineering workforce in an integrated, interdisciplinary research environment where academe and industry join in partnership to advance fundamental engineering knowledge, enabling technology, and engineered systems.

The National Science Foundation-sponsored Engineering Research Centers (ERCs) are interdisciplinary centers located at universities all across the United States, each in close partnership with industry. At the ERCs, academe and industry collaborate as partners in the pursuit of advances in complex engineered systems and systems-level technologies that could spawn whole new industries or radically transform the product lines, processing technologies, or service delivery methodologies of current industries.

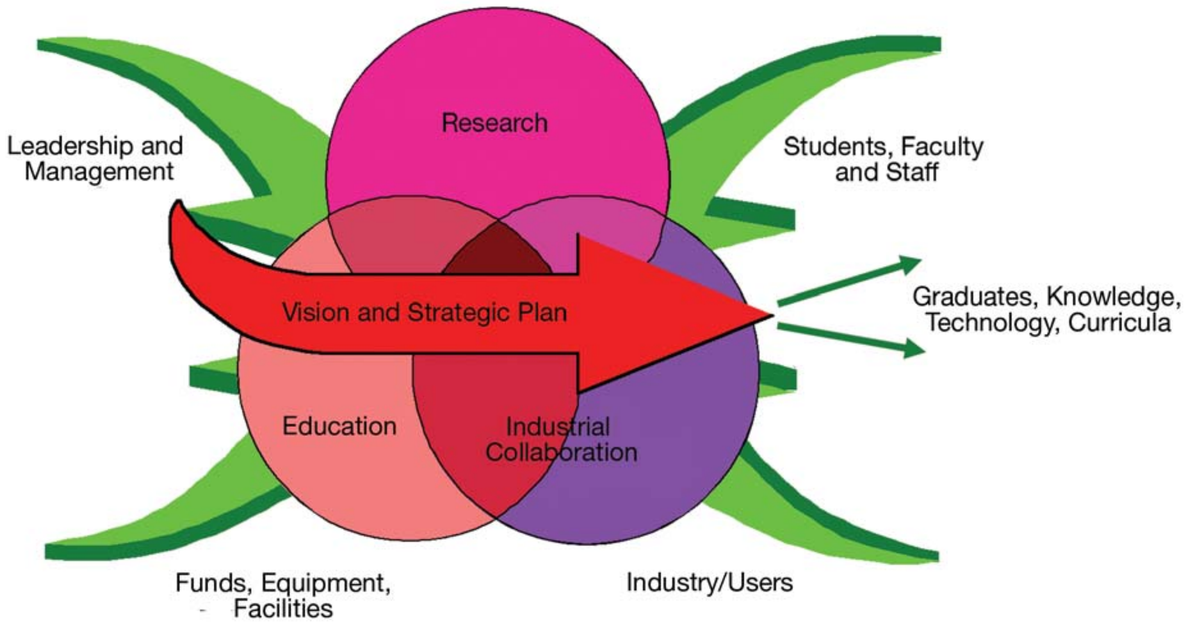
Because ERCs play a critical role in academe by integrating research, education, outreach, and industrial collaboration, NSF views ERCs as change agents for academic engineering programs and the engineering community at large. Indeed, over the past 20 years these centers have succeeded in changing the culture of academic engineering to include integrative collaboration across engineering and science disciplines, a greater focus on innovation and engineered systems, and closer interaction with industry. In the process they have revolutionized engineering education and produced a new generation of graduates who are adept at innovation and primed for technology leadership.

Every ERC* has a number of key features:

- A long-term strategic vision for an emerging engineered system, with potential to spawn a new industry or transform current practice;
- A long-term strategic vision to strengthen the diversity of the engineering and scientific workforce;
- Strategic plans to realize the research, education/outreach, and diversity goals;
- Research that integrates cross-disciplinary fundamental research with research to advance technology through proof-of-concept test beds employed to test theory in functioning systems.
- An education program that teams undergraduate and graduate students, and integrates research into the curricula for students at all levels as well as for practitioners;
- Precollege outreach that strengthens the role of engineering in the classroom and attracts diverse students to engineering;
- Partnership with industry and other practitioners to formulate, evolve, and strengthen the ERC and speed technology transfer;

* The three Earthquake Engineering Research Centers are very similar in structure and purpose to ERCs. Established in 1997, they were taken under management by the Engineering Education and Centers Division in 1999 and are included as ERCs in this report.

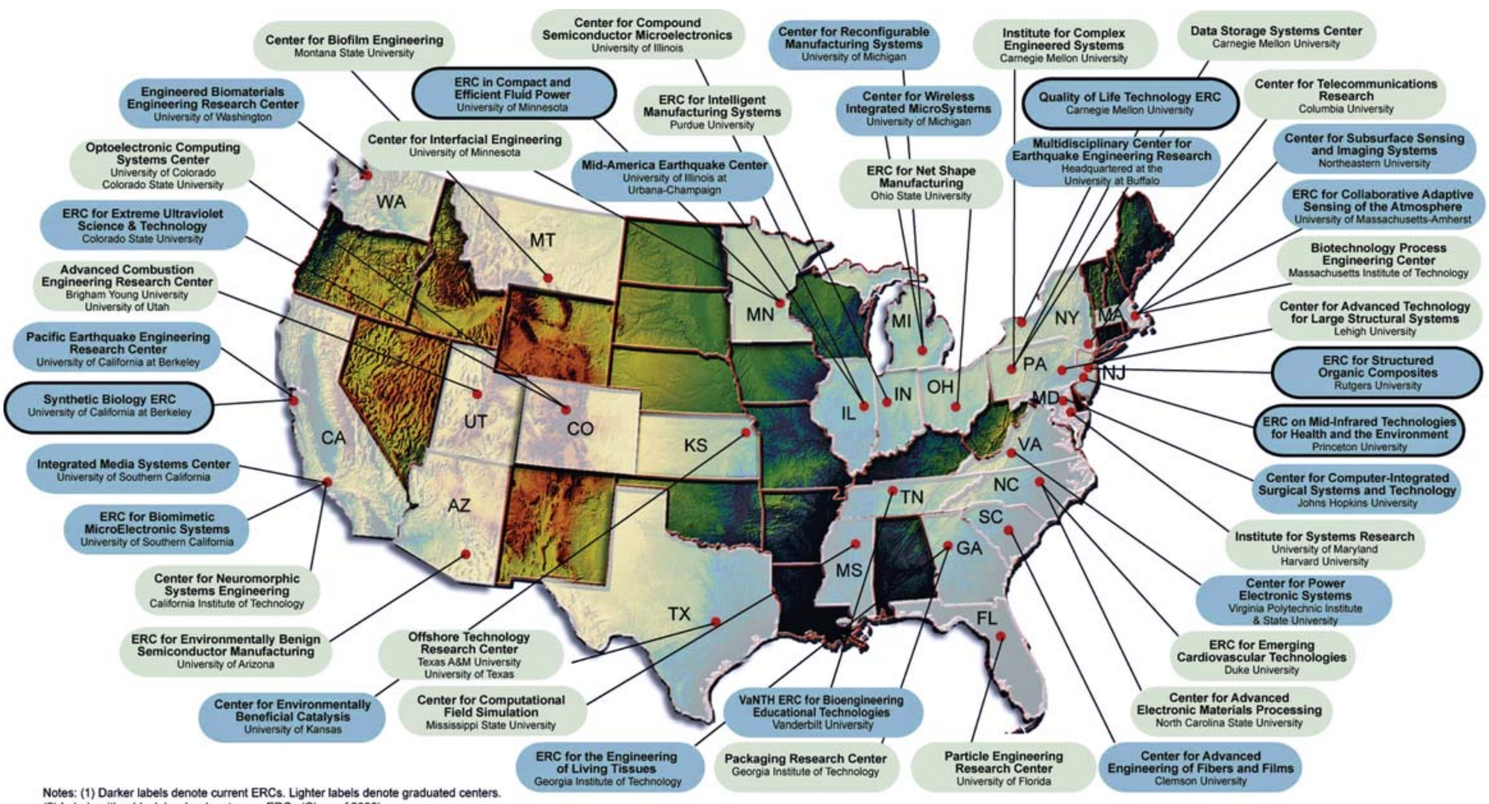
**An NSF Engineering Research Center - A Complex, Interdependent System**




As the figure above depicts, each ERC is a complex enterprise built on the three bases of research, education, and industrial collaboration, in which these key features interrelate to produce high-quality graduates, new knowledge, innovative technologies, and novel curricula derived from the unique systems approach of the ERC.

Since its establishment in 1985, the ERC program has evolved in concert with changing national needs and changes in the global environment for research and advanced development. As of the end of Fiscal Year 2006 there were 22 ERCs (including five newly formed ones), with 21 self-sustaining centers having "graduated" from the program after finishing their full 11-year life-cycle as an ERC. A map of the current and graduated ERCs is shown on page 6. The current ERCs are listed here by technology cluster. The map and a list of the centers with their partner institutions can be seen at http://www.erc-assoc.org/erc_affiliates_list.htm.

This 2005-2006 ERC Program Report describes significant events for the program and for the individual ERCs in every area of their activity.




Notes: (1) Darker labels denote current ERCs. Lighter labels denote graduated centers.
(2) Labels with a black border denote new ERCs (Class of 2006).
(3) Most centers are multi-university partnerships. University shown is lead institution.




## ERCs by Technology Cluster

### Bioengineering
- Synthetic Biology Engineering Research Center
- Quality of Life Technology ERC
- ERC for the Engineering of Living Tissues
- Center for Computer-Integrated Surgical Systems and Technology
- ERC for Biomimetic MicroElectronic Systems
- VaNTH ERC for Bioengineering Educational Technologies
- Engineered Biomaterials Engineering Research Center

### Manufacturing and Processing
- Center for Advanced Engineering of Fibers and Films
- Center for Environmentally Beneficial Catalysis
- Center for Reconfigurable Manufacturing Systems
- Compact and Efficient Fluid Power
- ERC for Structured Organic Particulate Systems

### Earthquake Engineering
- Multidisciplinary Center for Earthquake Engineering Research
- Pacific Earthquake Engineering Research Center
- Mid-America Earthquake Center

### Micro/Optoelectronics and Information Systems
- ERC for Extreme Ultraviolet Science & Technology
- ERC for Collaborative Adaptive Sensing of the Atmosphere
- Center for Wireless Integrated MicroSystems
- Center for Subsurface Sensing and Imaging Systems
- Integrated Media Systems Center
- ERC on Mid-Infrared Technologies for Health and the Environment
- Center for Power Electronics Systems


# Highlights of 2005–2006

On the fifteenth anniversary of the ERC Program, the then-Director of NSF, Dr. Rita Colwell, proclaimed, "One of the most daring experiments ever undertaken by the Foundation has been the ERC Program. This landmark program challenges the very nature of academic engineering research, engineering education, and university–industry collaboration. I am pleased to report that the experiment has been an unqualified success." Five years later, it continues to succeed.

During FY 2005 the ERC Program celebrated its 20th year in operation. While many federal government programs of that age are being "sunsetted," with 22 first-rate Centers this Program is as vigorous and dynamic as ever. Five ERCs graduated during this two-year period, and five new Centers were funded in FY 2006. These five were selected out of 109 pre-proposals received. Clearly, being an Engineering Research Center is still a coveted honor among U.S. universities.

Some highlights of the period are briefly described here.

## Research

At the University of Southern California's Biomimetic MicroElectronic Systems Engineering (BMES) Center, the search for implantable prosthetic devices to restore vision, locomotion, and other impaired functions took significant strides forward with the development of a novel low-power biomimetic mixed-signal integrated circuit as a key part of a platform for such devices. Center Director Dr. Mark Humayun was recognized by *R&D Magazine* as its 2005 Innovator of the Year for his work on retinal implants and for "his lifelong quest to help the blind to see."

Human ova die rapidly if not fertilized. Researchers at the Center for Subsurface Sensing and Imaging Systems (CenSSIS), headquartered at Northeastern University, have discovered a mechanism that seems to be correlated with this rapid death. As the window for fertilization passes, the distribution of mitochondria in the egg changes from evenly distributed to "clumped." Using a special microscope invented and built by the ERC, the researchers found that the mitochondria begin to swirl in a pattern they are calling a "mitochondrial storm," fatally altering the energy-distribution characteristics of the egg. Once this mechanism is fully understood, they hope to be able to inhibit the "storm," thus extending the time window during which eggs can be fertilized.

## Education

Nearly 10,000 students (from precollege to doctoral) participated in ERC education programs during 2005, when all 22 ERCs reported. Collectively, the Centers

*Students from UPRM and UMass set up an antenna for an 802.11 wireless link as part of both their experimental radar network and a hands-on undergraduate course.*

graduated 619 students in 2005, of whom 61% entered industry. (Graduates numbered 545 in 2006, when there were 19 reporting ERCs.)

During 2005 and 2006 an all-student team of 15 graduate and undergraduate students at the ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA), headquartered at the University of Massachusetts-Amherst, developed an experimental radar system, to be deployed in Puerto Rico, that will transform our ability to monitor heavy rainfall. This student-run testbed system—with nearly all the students coming from the University of Puerto Rico at Mayaguez (UPRM), a CASA partner institution—will cover a crucial 1.5 km-high gap in atmospheric weather-monitoring over western Puerto Rico that traditional radar technology cannot sense. Other innovations developed for the system include more accurate ways to measure rainfall and windspeed, and a novel power management scheme.

The Massachusetts Institute of Technology announced in 2005 the creation of an entirely new Biological Engineering (BE) undergraduate degree program. The program arose out of cross-disciplinary collaborations established some 20 years ago between biologists and biochemical engineers at the Biotechnology Process Engineering Center (BPEC). BPEC's Director and former Director were instrumental in bringing about the new degree program—the first to be established at MIT in 29 years.

### Diversity

Operating under a Program-wide diversity policy formalized in 2004, the ERCs continued to pursue efforts to increase the participation of women, underrepresented racial minorities, and Hispanics and Latinos in the Centers. In 2005 and 2006, the participation of all these groups exceeded national averages for engineering education programs—in some cases by a considerable margin.

### Industry

Industrial participation in strategic planning and funding of both research and education at ERCs is an essential part of what defines these Centers. In 2006, collectively

the 19 reporting ERCs had 268 total industrial memberships representing 225 separate companies. This ERC/industry collaboration results in a variety of forms of technology transfer. For example, in 2006 four new companies spun off from the ERCs, 108 inventions were disclosed, and 50 licenses to ERC-developed technologies were issued. Innovative products and processes derived from ERC discoveries continued to be put into practice. As just one example, in July 2006 General Motors installed a porosity inspection machine developed by the Reconfigurable Manufacturing Systems ERC on its automotive assembly line in Flint, Michigan—saving more than $500,000 per year in downtime and labor costs in this one plant. And Discera, a spinoff from the Center for Wireless Integrated MicroSystems, in December 2006 entered into partnership with a major Japanese electronics distributor to distribute Discera's CMOS MEMS resonator-based timing products worldwide.

**Academic Partnerships**

Most ERCs, and all ERCs funded since 1998, are multi-institutional (having a lead institution and one or more core partners). This diversity draws in a greater scope of expertise for collaboration in the research and broadens the educational impact of the Centers across more institutions and more students. In addition to the core partners, all ERCs are connected with several outreach institutions that provide a third circle of impact. In 2006 a total of 261 institutions, including 60 lead and core partners, were participating in the 19 reporting ERCs. Among the outreach institutions were 59 foreign universities in 26 countries—an indication of the increasingly global vision of the ERCs.

**Center Key Events**

In 2005 and 2006, the following five ERCs graduated from the program and became self-sustaining:

- ERC for Environmentally Benign Semiconductor Manufacturing (CEBSM), at the University of Arizona (lead institution)

- Center for Neuromorphic Systems Engineering (CNSE), at CalTech
- Packaging Research Center (PRC) at Georgia Tech
- Particle Engineering Research Center (PERC) at the University of Florida
- Biotechnology Process Engineering Center (BPEC), at MIT.

Five new ERCs were established to become the Class of 2006. They are:

- Synthetic Biology Engineering Research Center (SynBERC) – University of California at Berkeley (lead institution)
- Quality of Life Technology ERC (QoLT-ERC) – Carnegie Mellon University (lead institution)
- ERC for Compact and Efficient Fluid Power (CCEFP) – University of Minnesota (lead institution)
- ERC on Mid-Infrared Technologies for Health and the Environment (MIRTHE) – Princeton University (lead institution)
- ERC for Structured Organic Particulate Systems (ERC-SOPS) – Rutgers University (lead institution)

In 2006 the CenSSIS at Northeastern University received a gift of $20 million from The Gordon Foundation to establish an innovative model for educating engineering leaders, the Gordon Engineering Leadership Program. This will be an intensive one-year graduate program aimed at building an elite corps of engineering professionals. It will begin in September 2007. The gift will enable CenSSIS to be self-sustaining after graduation from ERC funding in 2010, and to evolve from an academic research center into an R&D center.

**ERC Program Management**

Total direct support for the 22 ERCs from all sources in FY 2005 was slightly over $120M, increasing to $151.2M in FY 2006. The ERC Program budget at NSF in FY 2005 was $56.3M; it increased to $57.5M in FY 2006. The grand total of ERC support from all sources was just under $200M in 2006. Of this, the great majority (62% in 2006) was allocated to research.


An ERC Program strategic planning effort undertaken in 2005 and 2006 led, among other things, to the definition of “Generation-3” ERCs. The Gen-3 ERCs will create a “culture of innovation” in engineering research and education that links scientific discovery to technological innovation through research on transformational engineered systems. Greater emphasis will be placed on partnerships with small, innovative firms and on encouraging entrepreneurship in students and faculty. These new ERCs will provide their faculty and students with global research and innovation experience through collaborative partnerships with foreign universities or other means, and will redouble their efforts to increase the enrollment of domestic students in engineering and science degree programs.

In November 2005, a glossy, large-format brochure was printed that described the ERC program for a general readership A two-page spread was devoted to presenting the mission and example accomplishments of each ERC.

A new ERC Best Practices Manual chapter on “Multi-university ERCs” was prepared and published in 2006. This chapter cut across all the functions and roles of an ERC and its staff, from the special perspective of multi-institutional operations.

**Annual Meeting**

The highlight of the 2005 ERC Program Annual Meeting was a keynote plenary talk given by Thomas Friedman, author of *The World Is Flat!.* This talk was an excellent catalyst for the meeting’s overall focus on globalization of engineering research, education, and technology development, and contributed to repositioning the ERC Program for the next decade.

The 2006 Annual Meeting continued the globalization theme, but with a more “hands-on” focus on new directions needed in education, industrial interaction, and center alliances to meet the challenges this paradigm shift poses. Several plenary talks gave concrete examples of how the “Global Engineer” thinks and operates.

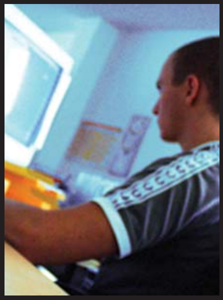
■ *Linda Griffith (left) and Lynn Preston at the 2005 ERC Program annual meeting.*

**Honors and Awards**

Lynn Preston, NSF's ERC Program Leader, was named a Fellow of the American Institute for Medical and Biological Engineering (AIMBE) for her leadership in helping to establish bioengineering as a major field in academe and industry, both through her efforts to initiate support for the field at NSF in the 1980s and the major investment of the ERC Program in exemplary bioengineering ERCs since 1985.

In 2006 the Director of the recently graduated Biotechnology Process Engineering Center, Linda Griffith, was named a MacArthur Fellow for her pioneering work and leadership in the field of stem-cell research—work pursued largely through the auspices of the ERC.

Research Advances



Education and Outreach

Improving Diversity in Engineering

Industrial Interaction

Academic Partnerships: A Global Network

# 2005-2006

## In Review

Center Key Events

ERC Program Management

Annual Meeting

Honors and Awards

# Research Advances

ERCs bring diverse engineering and scientific disciplines together to address fundamental research issues crucial to making technological advances in areas that will transform industrial practices or establish new industries to enhance the international competitiveness of U.S. industry in a global economy.

**All ERC Disciplines**

- Electrical, Electronics, Communications Engineering
- Mechanical Engineering
- Other Engineering
- Other
- Agriculture
- Health
- Computer and Information Sciences
- Education
- Linguistics
- Mathematics and Physical Sciences
- Social Sciences
- Bioengineering and Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer/Systems Engineering

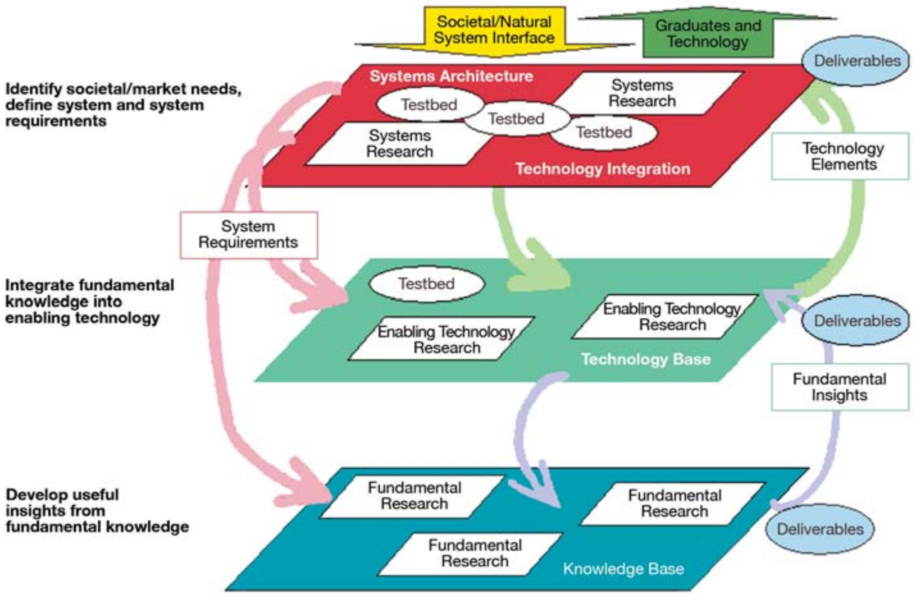
An ERC is a "three-legged stool" whose legs are research, education, and industrial interaction. Of these three foundations, research is the core activity without which no other component of an ERC can function. Research at an Engineering Research Center has a special character that is unique to these centers. It is inherently cross-disciplinary, being focused on an emerging engineered system with the potential to transform the field and/or the industries that the system will impact. Second, it blends fundamental work with more technology-focused efforts aimed at proving concepts underlying the new system. It follows a strategic plan developed in concert with industry. And finally, the research program is integrated with education programs offered through the center and its partner universities.

The disciplines contributing to ERC research are not restricted to engineering alone; they draw from all areas of the physical and social sciences, business, and even the arts and humanities that have a useful contribution to make in progressing toward the engineered systems goal. The figure to the left shows the wide range of disciplines that are actively involved in ERC research in FY 2006 across all the centers.

A primary organizing principle for the research at ERCs is a "strategic framework" that was developed by the ERC Program team in 1990. That framework is graphically expressed in a "three-plane diagram" (see figure at the top of page 17), which is a template on which every ERC bases its strategic plan for research. Each ERC devises its own custom-tailored variant of the diagram as a roadmap for its work. The figure to the right, the generic three-plane diagram, shows how the systems vision of the ERC drives a body of fundamental research and enabling technology needed to advance an engineered system.

## ERC Strategic Framework

*It's not an ERC if it doesn't do all three*




Like all academic research units and academic researchers, ERC faculty and to some extent the ERCs themselves are "graded" in part according to their research output and the publication of research results. In addition, a major objective of the ERCs is to stimulate the emergence of new industries and/or transform current industrial practices.

For both these reasons, disseminating the results of their research is a high priority for ERCs. As the table to the right shows, in 2006 alone the 22 ERCs averaged nearly 70 articles per center published in peer-reviewed journals and conference proceedings—of which over two-thirds included ERC students among the co-authors. Over the life of the program the total output of ERC publications has numbered in the tens of thousands. In addition, many thousands of symposia, workshops, and short courses have been organized by the centers, further expanding the "culture change" originally envisioned for this ground-breaking NSF program.

**ERC Information Dissemination FY 1985-2006**

| | FY 1985-2005 41 ERCs | | FY 2006 19 ERCs | |
|---|---|---|---|---|
| **Articles In** | **Total** | **Per Center** | **Total** | **Per Center** |
| Peer-Reviewed Conference Proceedings | 12,122 | 296 | 795 | 42 |
| Peer-Reviewed Journals | 12,850 | 313 | 571 | 30 |
| Trade Journals | 614 | 15 | 44 | 2 |
| Co-Authored with ERC Students | 3,679 | 90 | 1,148 | 60 |
| Seminars and Colloquia | 9,235 | 225 | 855 | 45 |
| Workshops Short Courses to Industry | 4,569 | 111 | 63 | 3 |

*(Below) A novel mixed-signal system on a chip as a versatile platform for implantable prosthetic devices.*

## Example Achievements in Research

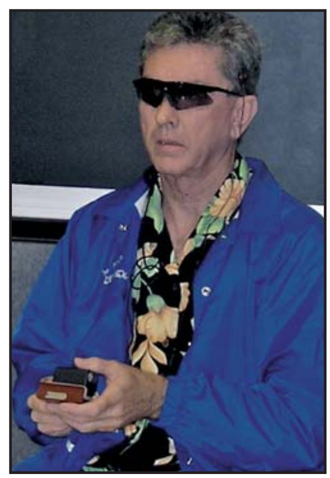
The myriad of research advances achieved by the ERCs and reported in FY 2005 and FY 2006 can perhaps be best illustrated by examples, chosen from the four technology areas or “clusters” into which the ERCs are divided.

### Bioengineering

#### ■ Systems-on-a-Chip for Powerful Prostheses

The Engineering Research Center for Biomimetic MicroElectronic Systems (BMES ERC), headquartered at the University of Southern California, is developing entire platforms for a range of implantable devices that could one day restore vision to the blind, reanimate paralyzed limbs, and overcome certain cognitive impairments. This new genre of implantable micro-electronic systems will seamlessly integrate with the human body and, in so doing, replace missing or damaged neuronal function. A large number of new technologies are needed to enable the realization of these implantable systems. The enabling technologies being developed range from wireless power and data to hermetic packaging and bioelectrodes, as well as novel low-power biomimetic mixed-signal very large scale integrated circuits (multifunctional VLSI chips).

As a highlight of development in one of these areas, the BMES ERC has made great strides in state-of-the-art mixed-signal systems on a chip. The device shown is an essential element of the technology needed to replicate neural functions using silicon chips. These new mixed-signal circuits will allow Center researchers to pack more functionality onto each chip, so that the same piece of silicon will hold both digital circuits inspired by neural processing and analog circuits able to communicate with actual neurons. Such a device has already successfully replaced the CA3 part of the hippocampus in the lab and in the future could also help meet the needs of an implanted retinal prosthesis that allows the blind to read and recognize faces.



■ *A recipient of the BMES’ prototype retinal prosthesis has regained some vision.*

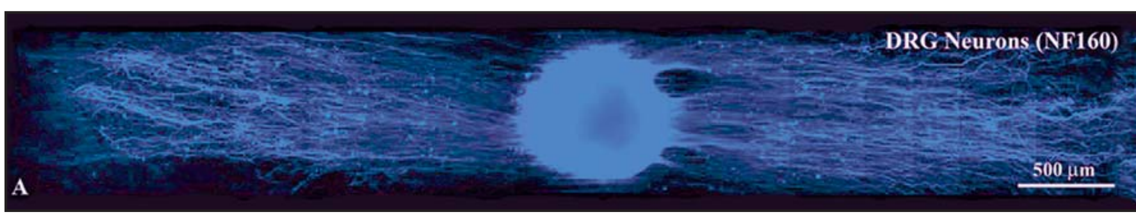
*(Below) Fluorescent image of chick neurites and neurons. Nanofibers were stacked with hydrogel spacers to form a 3D oriented nanoscaffold used to regenerate nerves across a 17mm nerve gap in rats.*

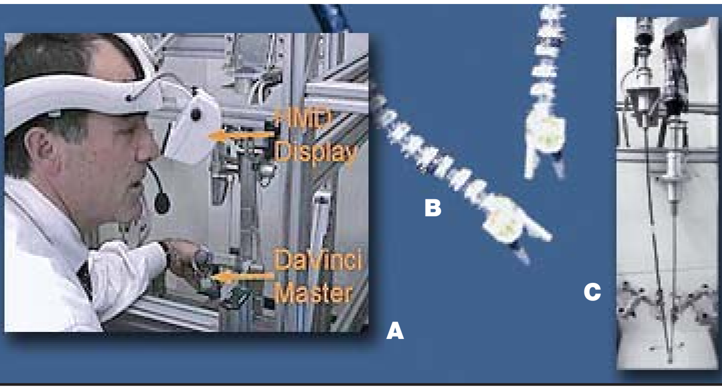
### Engineered "Scaffolds" Provide Biological Function

Researchers at the Georgia Tech/Emory University Center for the Engineering of Living Tissues (GTEC) use a combination of stem cell therapy and electrical stimulation to provide innervation and control of tissue-engineered constructs (or living tissue) such as muscle, bone, or skin. The constructs developed by GTEC include biological scaffolds for use in neural tissue-engineered applications. These structures are developed with the desired mechanical properties and can be used to engineer appropriate mechano-functional characteristics in the tissue.

GTEC researchers are developing several types of scaffolds for different purposes: (1) extracellular matrix protein and other hydrogel scaffolds to improve the survival of stem cells in vivo after transplantation following injury to the brain; (2) in situ gelling hydrogel scaffolds that serve as a vehicle for providing chemical and other cues that enhance the regeneration of nerves in the peripheral and central nervous system; and (3) 3-D scaffolds for use in "guided" nerve regeneration.

One example of the latter is a recent advance in oriented nanoscaffolds that holds promise for an engineered alternative to the use of autografts for peripheral nerve repair. The current standard practice for repairing peripheral nerve damage is to use nerve autografts to bridge nerve gaps. Unfortunately, there are many complications with autografts, both practical and medical. Having an off-the-shelf, engineered, polymeric graft that matches the performance of autografts, but without the complications, has long been a goal of peripheral nerve regeneration research. A GTEC group led by Ravi Bellamkonda has developed an oriented polymeric nanofiber-based 3-D scaffold that matches the performance of autografts in bridging a 17mm nerve gap model in animal subjects and shows promise for human clinical use.






*The CISST ERC Snake Robot. A) Dr. Paul Flint controls the robot by manipulating a daVinci master control arm while observing the surgical scene through a head-mounted stereo display; B) closeup of four-degrees-of-freedom snakes and grippers; C) the current two-handed prototype.*

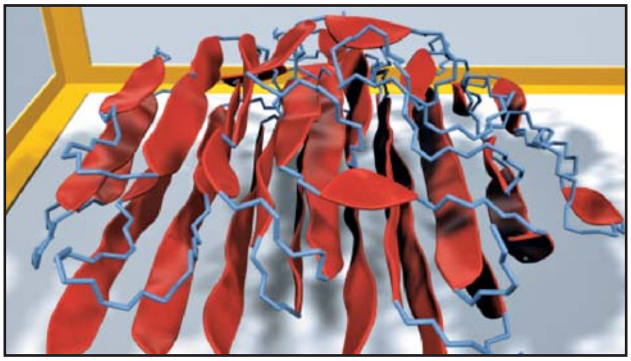
## A Snake-like Robot for Minimally Invasive Surgery

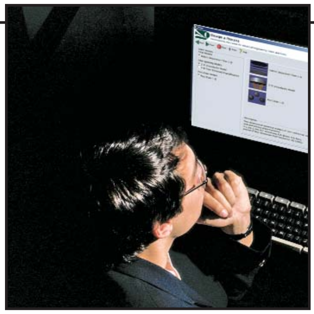
Manual use of surgical instruments is awkward for procedures such as surgery of the larynx that require high dexterity in a constrained workspace. The instruments are hard to manipulate precisely and lack sufficient dexterity to permit common surgical tasks such as suturing vocal fold tissue. Faculty members Russell Taylor, Peter Kazanzides, and Nabil Simaan along with several graduate students from the Johns Hopkins University-based Center for Computer-Integrated Surgical Systems and Technology (CISST) are developing "snake-like" robotic systems for minimally invasive surgical procedures in confined spaces inside the patient's body. For suturing inside the throat, the robot must be less than 5 mm in diameter—about the diameter of a soda straw.

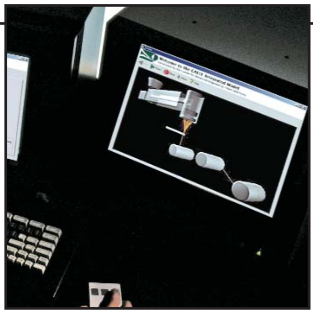
The project team is working closely with Dr. Paul Flint of Johns Hopkins' Department of Otolaryngology to develop a snake-like robot that uses flexible tool attachments and redundant ways to control the tools. This novel design makes it possible to build extremely small robots that can still apply the forces necessary to manipulate surgical instruments. The current prototype, shown in the figure, combines two 4-degrees-of–freedom tool manipulation units and two distal dexterity units, each with a 4-degrees-of-freedom snake-like wrist and a simple gripper. The surgeon uses two hand controllers from a daVinci surgical robot to teleoperate the snake manipulators while observing the surgical field using a stereo head-mounted display. The teleoperation control uses modular control hardware and a novel optimization-based formulation developed at Johns Hopkins. At the end of 2006, the team was preparing for comparative evaluations of surgeon performance using the robot versus freehand suturing through a laryngoscope.

The team anticipates applications of this family of robots in various surgical procedures, including laryngeal, eye, and skull base surgeries, as well as other minimally invasive procedures such as image-guided percutaneous ablation of tumors.

*Processes such as flow-induced polymer crystallization (right) can now be simulated using Center-developed software.*







## Manufacturing & Processing

### ■ New Models for Process Simulation

Fibers and films are special material forms that are commonly employed throughout the manufacturing industries. Designing and processing these materials is complex, as it must take into account their myriad forms and uses. Realistic simulation of these processes saves the manufacturer substantial time and cost.

The Center for Advanced Engineering Fibers and Films (CAEFF), headquartered at Clemson University, has created the first simulation package capable of predicting the final structure and properties of fibers or films produced under given sets of process conditions. The software simulates melt-spinning (the dominant commercial fiber formation process) of synthetic materials, using modules that simulate each stage of the process. It can be easily configured for a variety of processes. Menu-driven through a graphical user interface, the software features flow models at different levels of complexity, which enable the process designer to first gain insight with a quick, one-dimensional simulation. This knowledge is then used to set design parameters for more accurate simulations. The model is directly connected to the CAEFF Polymer Database, which serves not only as a medium for archiving experimental and simulation data, but also as a means of accessing all the material data necessary for a simulation by simply specifying the polymer.

### ■ Reconfigurable Inspection Machines in Factories

A key challenge for 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.

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

The ERC for Reconfigurable Manufacturing Systems (ERC/RMS) at the University of Michigan has developed a Portable Reconfigurable Inspection Machine (P-RIM) to meet this need. The P-RIM comprises a two-piece modular construction that is fully operational after a quick three-hour installation, set-up, and calibration. It uses 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.

The P-RIM is now on the factory floor in a Chrysler plant in Michigan, checking porosity on engine blocks and working there like a real industrial machine.

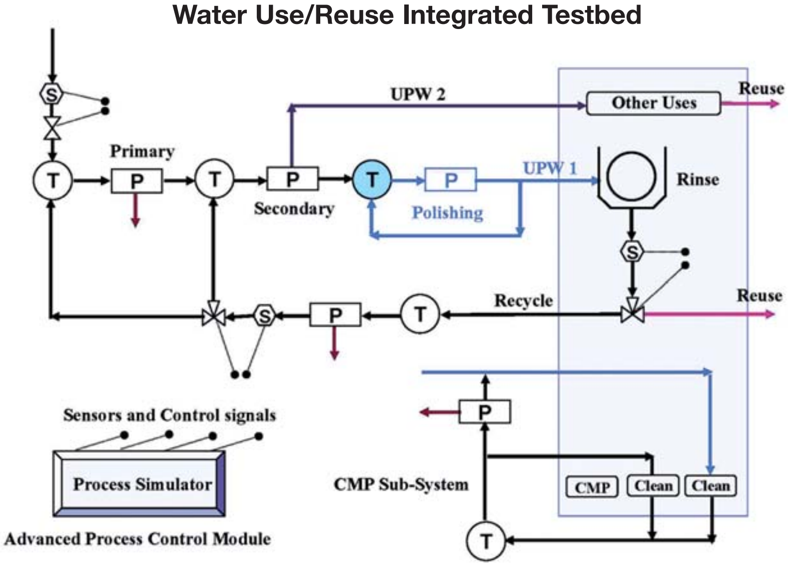
In July 2006, this technology made a significant leap forward. The knowledge base that was derived using the P-RIM was utilized by General Motors in the development of an industrial system for in-line surface porosity inspection of engine blocks that was installed in a production line in Flint, Michigan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

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 on the order of $100 million.

### ■ Reducing Water Use in IC Manufacturing

The growing 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

**Water Use/Reuse Integrated Testbed**



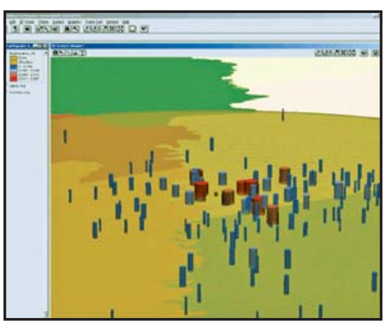

its partners, The Center for Environmentally Benign Semiconductor Manufacturing (CEBSM) at the University of Arizona set up a unique physical and simulation testbed facility that has allowed researchers to devise improved water conservation and recycling tools and techniques for IC fabrication. The goal was to provide technology that would make it possible to reduce water usage by 100% to 600%, depending on the fabrication technology being used. Achieving it has required a series of breakthroughs in water purification methods, use reduction, recycle, 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 recognized the contributions as "major innovations that have significantly impacted industry and society."

## Earthquake Engineering

### ■ Better Buildings via "Darwinian" Design Software

Protective technologies have revolutionized the design and retrofit of buildings for earthquake loads by absorbing damaging shock and vibrations. As building design evolves via use of advanced technologies, researchers at the Multidisciplinary Center for Earthquake Engineering Research (MCEER), headquartered at the University at Buffalo, are introducing a new computational platform that enables engineers to choose the optimal design and configuration to meet prescribed standards of performance for protection of the building and its contents. The Evolutionary Aseismic Design and Retrofit (EADR) software enables engineers to model a structure and encode its "genetic" make-up (its important structural and nonstructural attributes). A genetics-based evolution algorithm is then used to analyze and optimize the structure's dynamic behavior to attain the optimal level of performance for prescribed conditions.



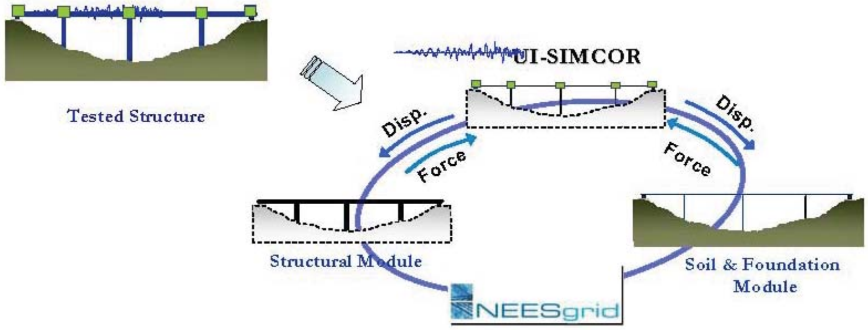
An initial beta version of the software for standalone PC is being used within the MCEER community of researchers and industry partners. This initial release of the software (EADR_1.0, in summer 2006) includes the capability to optimize the type, size, and location of passive damping elements in a structure subjected to an uncertain seismic environment. The seismic environment utilizes far-field and near-field synthetic ground motions based upon a commonly used seismic model for Eastern North America. Options provide for the specification of the design space of possible structures, drift and acceleration limits, and cost/benefit functions.

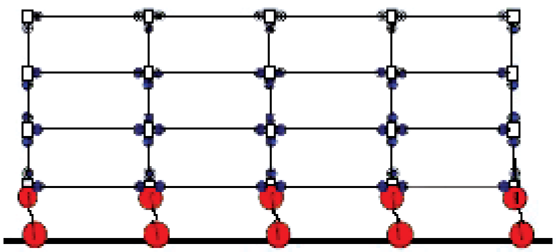
### ■ Quantitative Tools for Assessing Building Safety

Increasing the safety of populations in earthquake-prone areas is the ultimate goal of work at the Pacific Earthquake Engineering Research Center (PEER), at the University of California at Berkeley. In 2006, PEER took a step toward injecting its research findings into real-world commercial building practices.

PEER researchers have developed performance-based earthquake engineering framework and simulation tools that can be used to evaluate the safety of modern buildings as well as the seismic safety improvements

*Concept of multi-site hybrid simulation. The structural and geotechnical components can be numerically modeled or physically tested. There are no restrictions on the number of components, their nature, or their geographical location.*



■ *Actual building collapses in earthquakes can be simulated using PEER's framework and simulation tools.*

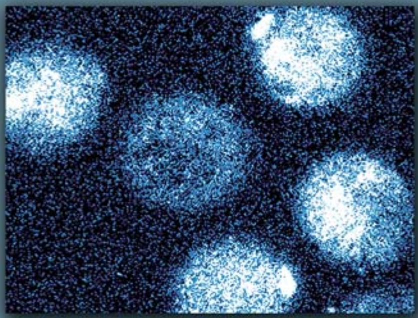
achieved by measures introduced in recent decades. Their studies show that changes to reinforced concrete building standards since the mid-1970s have cut the risk of collapse in modern buildings during seismic activity to one-twentieth the risk of older construction.

These quantitative assessment tools can help inform policy decisions about the benefits of retrofitting older existing buildings. Earthquake engineers can also use the tools to design more effective and less costly options to retrofit older buildings. PEER is working with industry and government partners to extend this methodology so that all building systems can be judged objectively and scientifically. The goal is to improve building uniformity and accelerate the introduction of new technologies for earthquake safety.

### ■ Earthquake Centers Create Framework for Collaboration on Simulations

Earthquake simulations are engineered at many unique and separate experimental sites and research centers. Each is a powerful generator of new data that can be pieced together to improve researchers' understanding of earthquakes. The simulations could be made even more powerful and informative if tied together more closely.

The Mid-America Earthquake (MAE) Center, headquartered at the University of Illinois at Urbana-Champaign (UIUC), teamed with other research centers to develop a framework, called UI-SimCor, that allows multi-site, multi-platform analytical-experimental simulations of



*The mitochondria of dying mammalian eggs swirl into clumps.*

soil-foundation-structure systems under seismic loading. The other contributing research activities are at Lehigh University and Rensselaer Polytechnic Institute.

UI-SimCor enables researchers to draw on the best and most appropriate experimental sites and analytical packages for structural and geotechnical modeling, without regard to location. The UI-SimCor framework enables collaboration between structural and geotechnical engineers and information technology specialists on analytical models, experimental specimens, and new tools to leverage the research.

### Micro/Optoelectronics and Information Systems

■ The "Mitochondrial Storm" in Mammalian Eggs

When a woman ovulates, there is only a short period of time in which the egg can be fertilized. Eggs that are not fertilized die. Researchers at the Center for Subsurface Sensing and Imaging Systems (CenSSIS), headquartered at Northeastern University, have discovered a mechanism that appears to be correlated with this rapid death: It is a "mitochondrial storm" that swirls as the egg begins to die, fatally altering the energy-distribution characteristics of the egg.

Professors Carol Warner and Badri Roysam lead two collaborating CenSSIS groups. Warner's group is investigating the mechanisms that are responsible for the death of unfertilized eggs by using a mouse model system. They are concentrating on the role of the energy-producing organelles in the eggs that are called mitochondria. They found that the spatial distribution of mitochondria in the eggs is a good indication of the ability of the eggs to be fertilized. A smooth distribution is found in healthy eggs and a clumped distribution is found in eggs that can no longer be fertilized.

Recently, Warner's group expanded this static view of mitochondrial distribution to a dynamic view with the aid of a unique instrument, the Keck Three-Dimensional Fusion Microscope, which was invented and built at Northeastern under the auspices of CenSSIS. By using a special culture chamber, the researchers have been able to visualize, with time-lapse photography, the changes in mitochondrial distribution that occur for 24 hours after the time in which the eggs would

*The integrated modular motor drive is the harbinger of future "smart" motor drives that deliver higher performance and reliability at lower cost.*

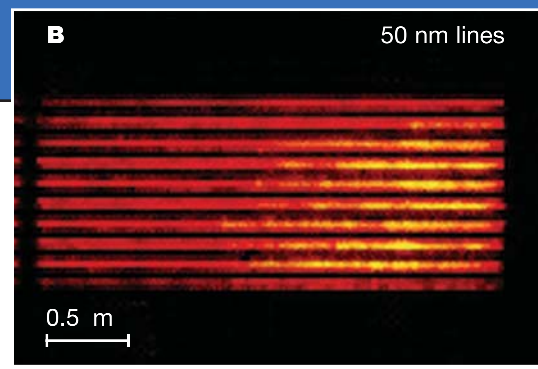
normally be fertilized. They have found that the mitochondria swirl in a cyclonic pattern that is reminiscent of a tropical storm. This "storm" indicates that the mitochondria are assuming a clumped distribution and that the egg is about to die. Roysam's group is working on mathematical methods to process the mitochondrial storm data using motion analysis and measures of "clumpiness."

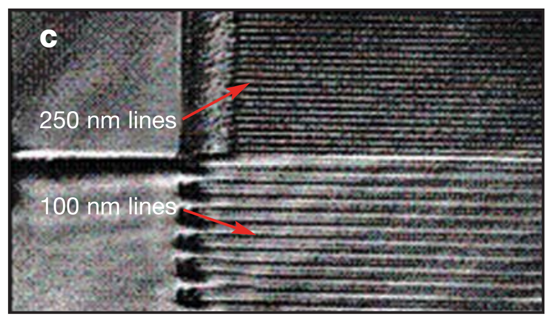
After the researchers understand the mechanisms leading to this mitochondrial storm, they hope to be able to inhibit the storm to extend the time during which the eggs can be fertilized. This will be a powerful tool for the roughly 400 in vitro fertilization clinics that currently exist in the United States and should offer substantial benefit to the one-in-six American couples who currently suffer from fertility problems.

■ Integrated Modular Motor Drive (IMMD)

The Integrated Modular Motor Drive (IMMD) is a new motor drive architecture that promises reduced cost and increased reliability. The motor is constructed from a number of modular phase-drive units interconnected in a ring to form the electrical core of the motor. Each of these phase-drive units includes both the iron pole piece with its winding and an integrated power electronic module (IPEM) attached to the end of the pole piece inside the motor housing. By eliminating the need for a separate housing for the motor drive electronics, the resulting "smart" motor reduces the losses associated with the cables used to connect external drive electronics to the motor, thereby increasing performance. By allowing standardization and high-volume production, modular phase-drive units promise reduced manufacturing costs. The modularity of the IMMD allows the motor drive to continue operating when one or more of the phase-drive units fails, improving overall drive reliability.

Several technology innovations achieved at the Center for Power Electronics Systems (CPES), headquartered at the Virginia Institute of Technology and State University, will be incorporated into the IMMD, including the elimination of electrolytic capacitors and the use of integrated current and temperature sensors inside the IPEMs. Based on these advances, CPES is aggressively pursuing the IMMD architecture as the template for future generations of low-cost, robust motor drives.


*A) Schematic representation of the EUV laser microscope;*

*B) image of a 50 nm half-period grating obtained using 13.2 nm wavelength laser light for illumination;*

*C) image of computer chip obtained using 46.9 nm wavelength light illumination. (The computer chip sample was provided with permission by AMD Corporation.)*

## New Microscope Opens Views of the Nano-world

The extension of optical microscopy to resolve features with dimensions down to tens of nanometers will have a major impact on nanoscience and nanotechnology. The resolution in broad-area images acquired with light-based microscopes is limited by the wavelength of the light. Therefore, the use of extreme ultraviolet (EUV) light, corresponding to wavelengths 10 to 100 times shorter than visible light, has the potential to yield microscope images with much greater resolution. Currently the best spatial resolution for compact light-based broad-area microscopes is just under 200 nm. Researchers at the ERC for Extreme Ultraviolet Science and Technology (EUV ERC) have recently obtained sub-38 nm resolution images using a microscope that combines the 13 nm wavelength light output from a new tabletop EUV laser developed at Colorado State University with diffractive optic lenses developed at Berkeley. These lenses, called "zone plates," consist of a set of very small concentric rings that alternate between opaque and transparent, and perform somewhat like a circular diffraction grating. The high brightness and directionality of the new high-repetition-rate EUV lasers makes it possible to

*Lasers using extreme ultraviolet light hold the key to visualizing features at the nanometer scale.*

efficiently collect and focus the light onto a sample, allowing for the imaging of nano-scale features within a short exposure time.

The EUV microscope system is schematically shown in (a). The spatial resolution of the microscope is better than 38 nm, a world record for a tabletop-size light-based microscope capable of obtaining broad-area images. A very compact alternative configuration of the instrument that uses a discharge-based EUV laser operating at a wavelength of 46.9 nm has also been implemented. This desktop-size microscope can render broad-area images of nanoscale features on integrated circuits, using exposures of only several seconds. The resolution of the microscope can be further improved by using an objective zone plate with smaller outer zone width. In addition, the high brightness and the picosecond pulse duration of the compact EUV laser will allow imaging of samples undergoing rapid changes.

These advances open a path to the realization of very high-resolution (e.g., 10-20 nm) compact analytical imaging tools that will in turn provide a new window on the nanoscale world.

# Education and Outreach

Over the past 20 years, the ERCs have revolutionized engineering education and produced a new generation of graduates who are adept at innovation and primed for technology leadership.

A major goal of the Engineering Research Centers program is to ensure that the education of engineering students prepares them to be leaders in innovation in industry as well as academe. The aim has been to produce engineering graduates who are able to apply their knowledge across disciplines to advance technology based on first-hand experience with systems, which is vital for industrial innovation. Several facets of the ERC educational environment contribute to their success in achieving this aim.

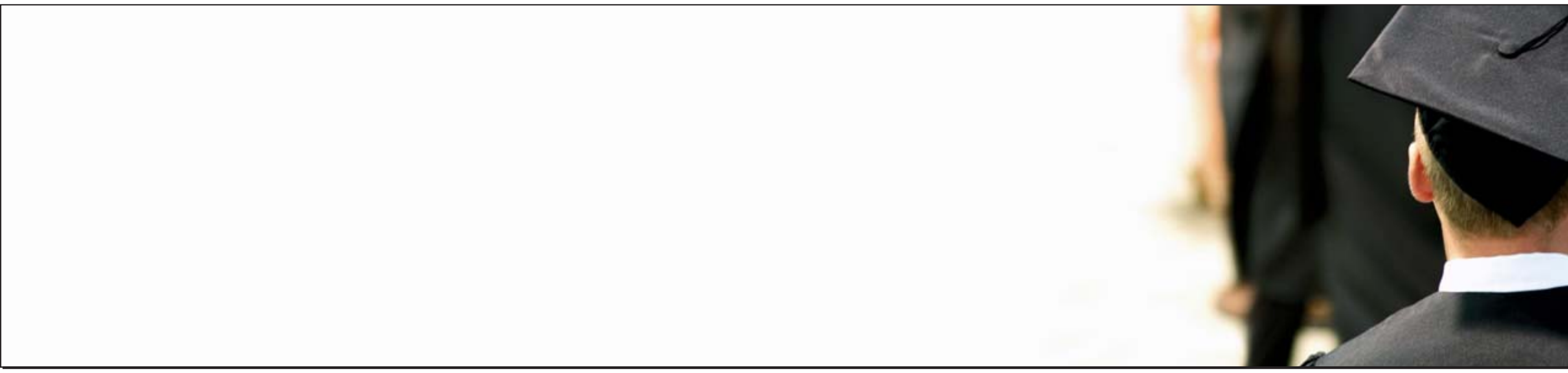
**Degrees Granted to ERC Students FY 1985-2006**

| | FY 1985-2005 41 ERCs | | FY 2006 19 ERCs | |
|---|---|---|---|---|
| Degree Type | Total | Per Center | Total | Per Center |
| Bachelor's Degree | 3,595 | 88 | 164 | 9 |
| Master's Degree | 3,325 | 81 | 175 | 9 |
| Doctorate Degree | 3,219 | 79 | 206 | 11 |
| Totals | 10,139 | 267 | 545 | 29 |

First, ERC faculty, students, and industry partners integrate discovery and learning in an interdisciplinary environment that reflects the complexities and realities of real-world technology. Second, ERCs expose prospective students (both graduate and undergraduate) to industrial views in order to build competence in engineering practice and to produce engineering graduates with the depth and breadth of education needed for success in technological innovation and for effective leadership of interdisciplinary teams throughout their careers. Third, ERC innovations in research and education are expected to impact curricula at all levels, from precollege to life-long learning, and to be disseminated to and beyond their academic and industry partners.

Accordingly, ERCs also build programs of precollege outreach to help ensure that new generations of students have the opportunity to pursue careers in engineering. Further, outreach to population groups traditionally underrepresented in engineering helps to ensure that the nation draws its engineering talent from the broadest possible pool.

In 2006, across the 19 reporting ERCs, on average nearly 400 students at all levels (including precollege



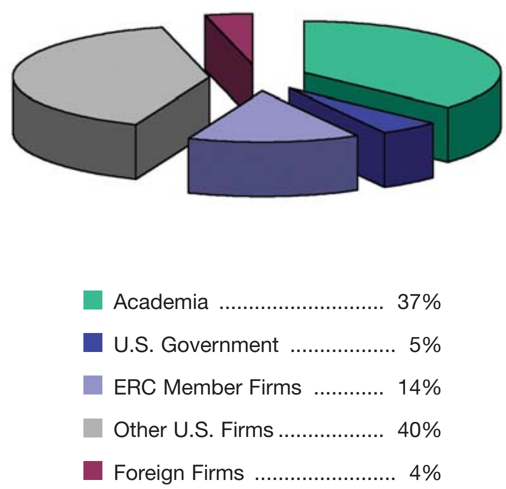
students and teachers as well as university-level students) participated in education and outreach programs at each Center. The total of 7,343 students in this one year alone (9,595 in 2005, when 22 ERCs were reporting) represents a significant impact on engineering-oriented education in the United States.

### ERC Graduates: Degrees and Placement

In 2006, as the table to the left depicts, all the ERCs together graduated 545 students, or an average of 29 degrees per center. The degrees are granted through the departments, but the students typically take numerous ERC-generated courses and conduct their research in Center labs with Center faculty and students.

ERC graduates move into all sectors of engineering employment, as the chart to the right displays. Given their close association with industry during their education and the quality of the training they receive, ERC graduates are highly sought-after by industry. In 2006, 58% of all ERC graduates went into industry. It is also a testament to the value placed on interdisciplinary capability and the capacity to lead in innovation in academe that 37% of the 2006 graduates of these cross-disciplinary research organizations entered faculty positions.

**ERC Graduates by Employment Sector**
**FY 2006**



## Undergraduate Education

The ERCs were the first NSF-funded academic research units to routinely involve large numbers of undergraduates in the research, as members of the research team. By integrating them into the research team along with graduate students, postdocs, faculty, and even industrial partners, the ERCs are able to bring research and education together in powerful new ways, greatly impacting the quality and relevance of the undergraduate educational experience.

While every ERC conducted a variety of education programs focusing on undergraduate education in 2005 and 2006, a selection of outstanding examples can convey the innovative nature of these programs and their effectiveness.

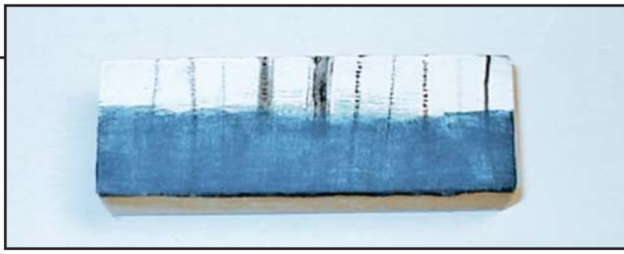
### ■ Hands-on Surgery Course For Engineers

The Center for Computer-Integrated Surgical Systems and Technology (CISST), headquartered at The Johns Hopkins University, prepares engineering students to invent and develop advanced medical technologies. CISST's "Surgery for Engineers" course engages students in new and exciting learning experiences, builds bridges between engineers and medical practitioners, identifies and solves real-world problems using engineering principles, and strengthens the undergraduate curriculum in terms of career preparation. This course teaches engineering students the fundamental skills and operative procedures for general surgery. It is a hands-on course that is designed for engineers who are developing computer-integrated surgery tools that will improve upon current technologies in use in the Operating Room. The undergraduate gets a hands-on laboratory experience that is unlike any other in their courses, and that challenges them to continue this experience into their research at the graduate level.

### ■ CenSSIS Undergraduates Work with Museum to Image Art

How can you distinguish between a painting by an old master and a modern forgery? Sometimes the clues to artistic mysteries are in hidden features beneath the superficial layer of paint.

*(Right) Earthquake professionals anticipate the imminent collapse of a structure during the 2006 Undergraduate Shake Table Competition.*



■ *In the CenSSIS MFA project, a wooden block is painted white and lines are drawn using graphite and other materials. The lines are then painted over with different colors and types of paint. Confocal reflectance imaging is used to detect the lines beneath the paint.*

Under the direction of Dr. Gary Laevsky, undergraduate students at the Center for Subsurface Sensing and Imaging Systems (CenSSIS), headquartered at Northeastern University, began working in 2005 on an imaging project to help the Boston Museum of Fine Arts (MFA) with information about hidden features relating to artwork. The project uses 2-Photon microscopy. Two potential applications for this research will be to examine the feasibility of discerning under-drawings hidden beneath completed paintings and to examine layers of furniture finish to determine its age and composition. During the year these "CenSSIS Scholars" were working with MFA curators to characterize samples of wood blocks with pencil sketches under painting and wooden blocks with multiple layers of shellac.

## ■ Undergraduates Take Earthquake Engineering Contest to National Stage

Undergraduates at the University of California at Berkeley have expanded a competition they started at the Pacific Earthquake Engineering Research Center (PEER) to involve their peers at other institutions, as well as professionals in the field. PEER's Student Leadership Council organized the annual Undergraduate Shake Table Competition in 2004, challenging civil engineering students to construct structural models that perform well under earthquake simulations. Practitioners and judges rate teams on an oral presentation, the design's performance, technical merit, and economics.

In 2005, the PEER students invited into the competition their peers from the MCEER at the University at Buffalo and from the Mid-America Earthquake Center at the University of Illinois at Urbana-Champaign, two other ERCs.

In 2006, the students took the competition to the national level—at the 8th US National Conference on Earthquake Engineering, where it attracted an audience


*The student-run radar network consists of a CASA "rooftop radar" (coverage shown by blue circle) located at UPRM; and CASA "off the grid" radars (pink circles) that will be deployed at remote locations to fill in a low-level coverage gap that the island's only WSR-88D Doppler radar cannot "see."*

of professionals and conference sponsors. This competition gives students opportunities to test out and gain a better understanding of what they've learned in the classroom. Competing at a national conference exposes them to career opportunities in earthquake engineering, and gives them a chance to mingle with professionals who could prove to be good contacts later on.

### Graduate Education

Graduate education in ERCs, being oriented toward engineered systems, is both specialized and diversified. In addition to an immersion in the fundamental sciences underlying their systems focus, students gain a broad multidisciplinary perspective via the team approach to developing system testbeds. Through research on these testbeds and through collaboration with industrial researchers they gain real-world, hands-on experience in technology development. They acquire an understanding of what it takes to commercialize ERC innovations through the involvement with industry, both established and start-up firms, as well as through university-led business development programs that help students develop business plans and learn how to market ideas to venture capital organizations. ERC graduate students also gain leadership experience by working in significant project management roles, by mentoring undergraduate team members, and by playing an active role in their Student Leadership Councils.

Some examples will serve to illustrate these unique features of an ERC graduate education.

#### ■ Students Design Advanced Radar Network

An all-student team of 15 graduate and undergraduate students at the ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA), headquartered at the University of Massachusetts, Amherst, spent much of their time during 2005 and 2006 creating an experimental radar testbed system, to be deployed in Puerto Rico, that will transform our ability to monitor heavy rainfall. Comprised of an array of miniature radar sensors, the system produces accurate rainfall data to be used to predict flooding and support other applications such as crop hydrology that require accurate rainfall estimates. The radar system should be operational by mid-2007.

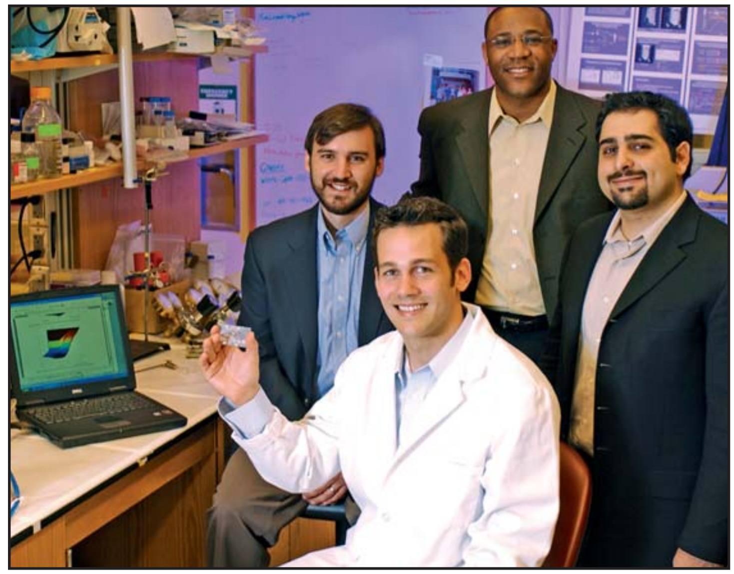
The student-run testbed system, with graduate students leading the project team, offers both a unique research and educational experience. It requires students to

■ *A CASA student-designed radar network being installed in Puerto Rico produces accurate rainfall data that will be used to predict flooding and support other applications such as crop hydrology that require accurate rainfall estimates.*

work across disciplinary and geographical boundaries and understand all facets of developing and implementing a testbed. The fully operational system will cover a crucial 1.5 km-high gap in atmospheric weather-monitoring over western Puerto Rico that traditional radar technology cannot sense. The testbed also will explore methods for more accurate measurement of rainfall and wind data than is now possible. And it could be used as a back-up to the current radar system if the Puerto Rican electrical grid blacks out in heavy weather. One of many student design innovations is a system for allocating power-hungry activities (such as computation) to nodes with more reliable access to power, to minimize downtime.

The innovative nature of this testbed and its new paradigm for power distribution led CASA to develop a new research theme. Thus it is a prime example of the central involvement of students in ERC research. The project also exemplifies the power of multi-university collaboration and its impact on education, as most of the students are from CASA partner UPRM (University of Puerto Rico, Mayaguez).

*GTEC PhD student Jeffrey Gross (front) has developed new technology to improve the treatment of diabetes. The other TI:GER team members shown with him are developing a plan to market this invention.*



■ Training for Bioscience Commercialization Through TI:GER Teams

To bring into the commercial market technical innovations that require skills from a variety of disciplines, the Georgia Tech/Emory Center (GTEC) for the Engineering of Living Tissues joined forces in 2005 with the PI of an NSF IGERT* grant, Dr. Marie Thursby in the Georgia Tech College of Management, in a commercialization program called “Technological

* *Integrative Graduate Education and Research Traineeship.*


Innovation: Generating Economic Results" (TI:GER) (http://tiger.gatech.edu/). The two-year TI:GER program educates graduate students in the challenges of commercializing new technologies and delivering innovative products to the marketplace by combining classroom instruction, team-based activities, and internship opportunities. Each TI:GER team is composed of a science or engineering Ph.D. candidate, a Georgia Tech MBA student, and an Emory Law student. Currently, there are 9 bioscience-related TI:GER teams, 7 of which have been formed around faculty inventors from GTEC.

GTEC industry members will have the opportunity to interact with a select group of TI:GER teams that will give them short summary "pitches" of their projects. The advantages of this interaction with industry are: 1) the commercialization teams will receive feedback from highly experienced industry partners; 2) the industry partners will be exposed to development plans and progress in GTEC and bioscience innovations; and 3) industry members will meet Ph.D., MBA, and JD students who could become valuable employees with industrially relevant experience.

### ■ Research Team Studies Effects of Kashmir Earthquake

The Pakistani province of Kashmir was rocked with a 7.6 magnitude earthquake on October 8, 2005, killing more than 80,000 people, injuring 70,000 and causing possibly $15 billion in economic losses—enormous damage for this area of the world. Researchers at the Mid-America Earthquake (MAE) Center, headquartered at the University of Illinois at Urbana-Champaign (UIUC), quickly organized a trip to the affected area to learn as much as possible from the event.

Conditions on the ground were startling. Some rivers had changed course or were completely blocked, forming precariously unstable lakes. Entire towns were demolished. However, only a few fully engineered structures suffered extensive damage, including a hospital that showed the effects of poor construction practices despite being built with high-quality materials.

The team met more than 80 officials in government, universities, the Army, and private businesses over the course of the seven-day trip, which has resulted

*The aim of programs focused on precollege students is to raise their awareness of engineering and their potential interest in pursuing an engineering career—whether at the ERC or elsewhere.*

in a joint U.S.-Pakistan research project. Sung Jig Kim, a PhD candidate at UIUC and a member of the field team, asserted that the trip and the follow-up work were beyond merely educational—it was "a life-transforming experience" for him.

**Outreach**

ERCs reach out to *undergraduate students* across the country to involve them in the excitement of research in an interdisciplinary team culture. NSF's Research Experiences for Undergraduates (REU) summer program was inaugurated in 1985, and from its beginning all ERCs have offered REU opportunities. These efforts stimulate interest in the ERC's field of research among a wider spectrum of students, often including students from population groups traditionally underrepresented in engineering, such as African Americans, Native Americans, Hispanic Americans, women, and persons with disabilities. There were 383 REU participants across the ERCs in summer 2005. Of these, 45% were female; 20% were racial minorities; and 18% were Hispanic. (The total dropped to 276 REU participants in summer 2006 because five ERCs had graduated and the five new ERCs were not yet fully operational.)

The aim of outreach programs focused on *precollege students* is to raise their awareness of engineering and their potential interest in pursuing an engineering career—whether at the ERC or elsewhere. In 2006, some 6,207 K-12 students participated in ERC outreach programs. ERCs also involve *precollege teachers* through workshops and laboratory experiences to inform them about engineering research and design challenges. These teachers are then able to incorporate engineering concepts in their classroom lessons to stimulate students' awareness of engineering as a field of endeavor and a possible career choice. In 2006, the ERCs directly impacted 236 precollege teachers.

The purpose of outreach programs mounted for the *general public*, such as museum exhibits, is to increase public awareness of science and engineering and of the field in which the ERC is active. Finally, ERCs disseminate their research advances and new knowledge to the *academic and professional engineering* worlds through a variety of means, including hosting conferences and symposia and offering short courses.

*Two Native American students who participated in the 2005 BMES ERC externship program with Pima Community College.*

Some examples from 2005 and 2006 in all of these areas follow.

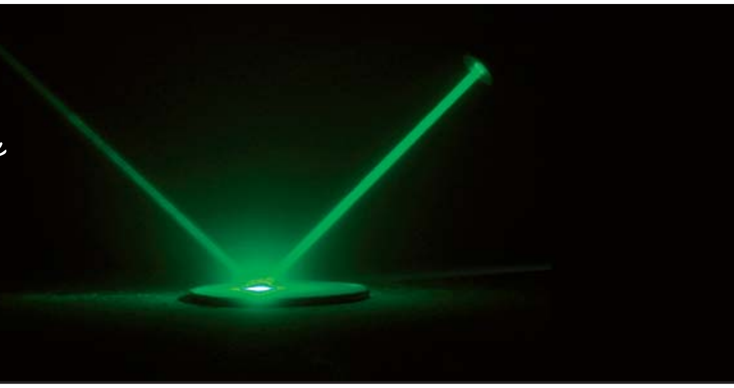
■ Externships for Native American Students

The ERC for Biomimetic MicroElectronic Systems (BMES), headquartered at the University of Southern California (USC), has formed a partnership with Pima Community College (PCC), in Tucson, Arizona. PCC is the only federally recognized minority-serving institution in Southern Arizona. In 2004, BMES created a pilot program that brought two PCC students to USC for two weeks during the summer. In summer 2005 two more PCC Native American students, Tatiana Halwood and Walter Jacobson, participated in the externship program. The Center's REU program coordinator and students worked closely with Tatiana and Walter to incorporate them into the REU team. Both of these students plan to attend medical school and are interested in research. Both are majoring in Molecular and Cell Biology in a joint program between PCC and the University of Arizona. In summer 2006, PCC students Isaac Frazier and Naomi Lupe participated as part of the two-week BMES Tribal Colleges and Universities (TCUP) REU program.

The experiences that these Native American students gained during the summer ranged from exposure to the reality of life in an urban metropolis to research at a world-class institution. They shadowed researchers in BMES, learning first-hand about the Center's work. The students met with BMES ERC Industrial Liaison Officer Dr. Howard Phillips—who proved a particularly inspiring role model, as he is a Native American himself. (A member of the Choctaw Nation of Oklahoma, Dr. Phillips is the only member of his tribe known to have earned an advanced degree in engineering.) Tatiana and Walter observed procedures related to the Retinal Prosthesis Testbed, met retinal implant patient Terry Byland, mentored Murchison Elementary students alongside REU and STAR students for BMES' Summer Science Day, and received individual pre-med advising at the Keck School of Medicine. Isaac and Naomi visited BMES partner institution Caltech and saw first-hand the research being conducted there.

BMES plans to continue this collaboration for the duration of the Center, with the goal of institutionalizing the program at USC. In December 2005, the Center hosted Linda Andrews, a PCC Division Dean, on campus to visit with BMES administration and key faculty and tour its laboratories, giving her a first-hand sense of what her students have been experiencing at the ERC.

*High school teachers work on concepts related to lasers and light.*



■ Light and Optics Workshop for High School Teachers
The ERC for Extreme Ultraviolet Science and Technology (EUV ERC), headquartered at Colorado State University, considers highly interactive workshops for teachers to be one of the most effective ways to raise the science and engineering literacy of a large number of students. When teachers are educated in engineering design and in the inquiry-based scientific process, they can pass on the excitement and power of science and engineering to their students. In 2006 the EUV ERC presented a very successful workshop to 15 middle and high school teachers from Denver and Boulder counties. These school districts serve a large minority population. The workshop featured a variety of challenging experiments involving basic concepts in lasers and optics, designed to be performed using only equipment and materials commonly found in a public high school classroom.

The workshop encouraged a constructive approach where a physical phenomenon related to light was demonstrated and participants were asked to explain the fundamental concept through experimentation and discussion. Alternatively, predictions were made and then verified or disproved with experiments. These were highly effective and popular approaches that allowed participants a sense of discovery. Gaps in knowledge were quickly exposed and filled. Ultimately, the teachers were provided with sequences of questions and discussion points, which, in combination with experiments, can successfully lead their young students to discover the nature of physical phenomena in light/optics.

Quotes from the High School Teacher Workshop:

■ *"The workshop gave me a way to use hands-on activities to teach light and optics within a limited budget. This type of information is extremely useful to me as a teacher."*
■ *"The workshop offered logical instruction on why things behave the way they do (light, lenses, mirrors); the materials help provide a concrete basis for developing student activities; teachers leave with a fully tested tool kit."*
■ *"I found easy experiments and demos my kids can do with little guidance—very inquiry-based, and experiments that work every time."*
■ *"The workshop provided a user-friendly method, a good approach to use with students who have difficulty with abstract concepts."*
■ *"These activities make me think in ways I want my students to think."*
■ *"I leave with a clearer understanding of concepts that I only poorly knew of before."*
■ *"Each experiment built on the previous one; great individualized instruction."*
■ *"The best part of the workshop was the hands-on approach."*

*(Right) Participants watch as a student holds some of the hands-on props used to demonstrate principles of heart disease at the first Bioengineering Summer Camp.*

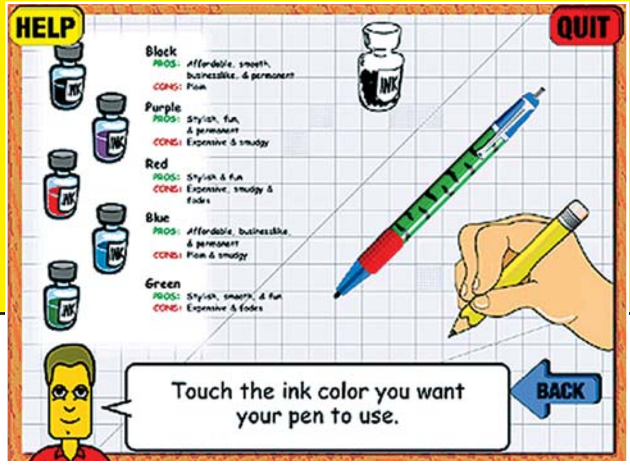
■ Summer Camp Introduces Young Students to Bioengineering

The future strength of the U.S. economy will depend on the ability of the country's next generation of scientists and engineers to maintain an edge over their peers in the developing economies of India and China. Unfortunately, U.S. students' interest and performance in science studies is on the decline. Also, women and minorities continue to be underrepresented in scientific and engineering fields, so we are not getting all we can from our citizens.

The University of Washington Engineered Biomaterials (UWEB) Engineering Research Center is working to spark an interest in science and technology among junior high school students. UWEB launched its first annual Bioengineering Summer Camp in 2005. The camp drew 28 students in the 8th and 9th grades, including some from communities that are underrepresented in the sciences. About 40 percent of the participants were young women.

A team of faculty and postdocs from the Center worked with high school teachers to design the camp curriculum. In particular, the group worked with junior high school teacher Mare Sullivan on a module about cardiac disease. In addition to brief talks and brainstorming sessions, the module gave students a

*Interactive games are an effective way to demonstrate to young students the concepts involved in manufacture of an everyday object such as a pen.*




chance to handle a circulatory model with defects that mimic disease states, and to hold and inspect stents, rotablators, and artificial heart valves.

### ■ Interactive Museum Exhibit Focuses on Manufacturing

Contemporary American youth are avid consumers of manufactured products. They are very familiar with a wide variety of available consumer products as a result of marketing campaigns, advertising media, and their own use of the Internet. However, as they buy and use today's products they most likely have no concept of how these products came to exist or how they were made. This knowledge gap suggests a need to educate the general public—and in particular young people—about what constitutes modern manufacturing.

An effort to bridge this technological knowledge gap is under way at the University of Michigan's ERC for Reconfigurable Manufacturing Systems (ERC/RMS). To extend its educational reach to the non-university population, the Center has designed and developed a museum exhibit highlighting the principles of modern manufacturing. The exhibit station consists of two main components: an exhibit kiosk, housing the physical displays and the computer equipment; and a set of interactive computer games. One goal of the games is to introduce children, especially girls, to the professions found in design, manufacturing, and business and to encourage them to consider careers in these fields.

The gaming software is aimed at a target audience of students in grades 6-12 and its content takes into account the audiences' perspective and level of understanding. The interconnected, interactive games of Design, Manufacturing, and Business outline the main processes in the development cycle of an example product—a customizable pen. The choice of a pen as an exemplary product was deliberate: it is a simple product, it is well understood, and yet it can illustrate the complex concepts related to design and manufacture. In the interactive parts of the game, the user is led through steps of market research, design selection, manufacturing, and marketing. Upon completion, the user is also given a brief test.

Installed in the Ann Arbor Hands-on Museum, the first part of the exhibit (Design Station) has been very successful. Throughout 2005 and 2006 it had several thousand visitors and continues to draw crowds.

*André Green is a sophomore in the first class of Biological Engineering majors at MIT. He will graduate in 2008.*

**Influence on Curriculum FY 1985-2006**

| | FY 1985-2005 41 ERCs | | FY 2006 19 ERCs | |
|---|---|---|---|---|
| **New Curricular Products** | **Total** | **Per Center** | **Total** | **Per Center** |
| Degree Programs | 131 | 3 | 2 | |
| Degree Minors Programs | 11 | | 3 | |
| Certificate Programs | 7 | | 1 | |
| New Courses | 722 | 18 | 38 | 2 |
| Modified Courses | 1,261 | 31 | 135 | 7 |
| Textbooks | 187 | 5 | 6 | |
| Course Modules | 253 | 6 | 76 | 4 |

## Curriculum Development

One of the most effective and highly leveraged ways for ERCs to disseminate the "culture change" in engineering education that they have always represented is through the development of innovative new curricula ranging from textbooks to course modules to new courses, to minors and certificates, to entirely new degree programs. With their cross-disciplinary systems focus, ERCs throughout the years have had a major impact on engineering curricula across the nation. 2005 and 2006 were no exception, as the table above displays.

Some interesting and high-profile examples of ERC curriculum development in 2005 and 2006 follow.

### ■ MIT's First New Field of Study in 29 Years

MIT, the institution that helped establish the academic fields of chemical engineering and electrical engineering, announced in 2005 the creation of an entirely new course of study with their revolutionary Biological Engineering (BE) undergraduate degree program. The program had its origins in cross-disciplinary collaborations established some 20 years ago between biologists and biochemical engineers when the faculty at the Biotechnology Process Engineering Center (BPEC) realized that there is a lot of fascinating—and necessary—research to do in the interface between biology and engineering. Their advocacy helped drive the establishment in 1998 of a new Biological Engineering Division at MIT, out of which the new degree program is a natural outgrowth. BPEC's Director, Linda Griffith, and former Director, Douglas Lauffenburger, were instrumental in shaping institutional consensus for the creation of the new degree program—the first to be established at MIT in 29 years.

The BE major started with just 20 undergrads and will grow in size over time as industry's demand for BE graduates expands.

*VaNTH researchers worked with precollege teachers to develop teaching modules based around such real-world concepts as the biomechanics of balance and gymnastics.*


### Bioengineering Teaching Modules Improve Precollege Science Test Scores

The Vanderbilt-Northwestern-Texas-Harvard/MIT (VaNTH) Engineering Research Center for Bioengineering Educational Technologies has as its main goal to develop an effective work force in bioengineering and is the only ERC devoted solely to the pursuit of innovations in engineering curricula.

In 2005, the VaNTH ERC continued its efforts to raise the interest and awareness of middle and high school students in bioengineering by working with precollege teachers to develop materials that present scientific principles through real-world examples. These teaching modules were based around the electrocardiogram; the biomechanics of balance as well as gymnastics; the optics of LASIK eye surgery; energy systems of the body as seen through the study of swimming, metabolism, and medical imaging; and fluid dynamics as illustrated through a study of hemodynamics.

Developed in Nashville, Chicago, and Austin public schools, the modules were implemented in high school physics and biology classrooms in one private school, two public magnet schools, and two public comprehensive schools. A statistical analysis of students' test results before and after the modules showed that they improve learning on basic science questions.

These modules were presented at national meetings such as the American Institute of Medical and Biological Engineering as examples of how to improve science learning in precollege students. The Center is presenting the modules to additional teachers through workshops and expects to extend the program to large school systems in Texas and California in the near future.

### LEGO Tutorials for Precollege Outreach

To increase participation in science, technology, engineering, and math programs by disadvantaged precollege students, the Center for Power Electronics Systems (CPES), an Engineering Research Center headquartered at the Virginia Institute of Technology and State University, has developed programs focusing on outreach to elementary and middle school students and teachers in rural southwestern Virginia. One such program, based on the FIRST™ Lego™ League (FLL) robotics challenge program, is intended to engage

precollege students in an ongoing Center project related to power controls and design. The CPES initiative provides participating teachers and students with on-site demonstrations, workshops, and mentorship by engineering undergraduate and graduate students.

In 2005, the CPES team completed development of five computer-based tutorial modules for use in the classroom. Each module consists of a beginner or “Basic” tutorial and an “Advanced” tutorial. Each tutorial unit consists of a homepage, an introduction, linked lessons, and a glossary targeting the second grade reading level. The modules—Problem Solving, Gears, Power, Sensors, and Programming—were created using FLASH software. In order to facilitate the integration of robotics into the classroom, the FLL contents have been aligned with the Virginia Standards of Learning. Teachers may access these standards and benchmarks for each grade, 4-8, for the justification of using the FLL program as a co-curricular activity. In Spring 2005, CPES conducted an in-school usability study, designed to solicit and incorporate teacher and student feedback on the modules. The tutorials will be available in 2007 through the CPES website and the Virginia FIRST Lego League organization.


■ *Metalloman*—a “Serious Game” for Teaching Science

The Integrated Media Systems Center (IMSC) at the University of Southern California has a research thrust on advanced educational and gaming technologies. During the 2005-2006 academic year, McKinley Technology High School in Washington, D.C., served as a living laboratory for the deployment of IMSC’s educational technologies into their classrooms and curriculum. Working with McKinley teachers and administrators, IMSC has used a “serious game” called *Metalloman* to teach complex science concepts.

*Metalloman* explores how learning can be conveyed through games without diminishing content, while

*Partnerships with precollege schools and teachers are an important means that ERCs use to bring more students into the engineering pathway.*

also focusing on how students can *play* with ideas and concepts central to the curriculum. Generally in a game, players are presented not only with information, but also with *experiences* from which information can be extracted as students are put into the picture of what they are studying. While that is more complex, it is often more engaging for players and students. The game was carefully designed to challenge users with tasks and activities that are tightly coupled to learning outcomes, while providing an engaging environment supporting curious exploration and an innovative learning experience.

The partnership with McKinley is proving mutually beneficial, as IMSC researchers are able to gather usability data to inform future designs as well as findings to support students' learning outcomes, while McKinley students and teachers are able to benefit from innovative educational applications and materials.

■ *To support 9th and 10th grade students preparing for the school's biotechnology academy, McKinley teachers and students have used the BioSIGHT™ Interactive Streaming Storyboard (ISS) tool developed by IMSC.*

# Improving Diversity in Engineering

ERCs fulfill NSF's strategic goal to increase the diversity of the scientific and engineering workforce by including all members of society, regardless of race, ethnicity, or gender, in every aspect of the centers' activities.

For many years one of the key features of the ERC program and of all the ERCs has been a determination to strengthen the diversity of the scientific and engineering workforce by encouraging members of population groups traditionally underrepresented in technical fields to pursue engineering studies. In 2004 this expectation was formalized in an official Program policy setting forth requirements for ERCs (shown at right).

Although numeric targets are not and cannot be specified, the general aim is for ERCs to exceed nationwide averages in academic engineering programs. This goal is pursued in many ways by individual ERCs and is now routinely achieved across the ERCs as a whole, as illustrated in the following series of charts.

As shown in the top chart on page 47, in 2006 ERCs exceeded by a considerable margin the percentage of women involved nationally in academic research and education. For example, 18% of all ERC faculty are women compared to about 7% nationwide. And about 36% of all ERC undergraduate students are women, compared to 21% nationally.

**ERC Program's Diversity Policy**

All ERCs will:

- Operate with strategic plans that include goals, milestones, actions and impacts aimed at increasing diversity at all levels to exceed national engineering-wide averages

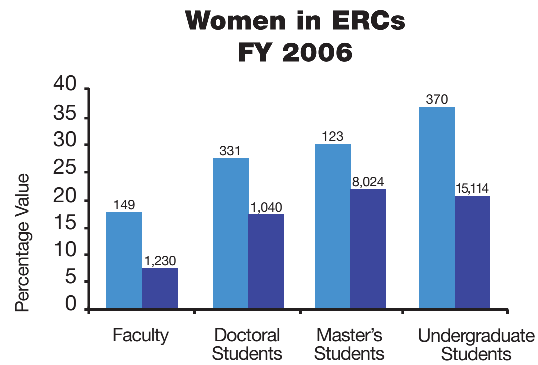
- Form sustained partnerships with affiliated deans and department chairs to enable this enhancement

- Develop core partner or outreach connections with predominantly female and underrepresented-minority institutions

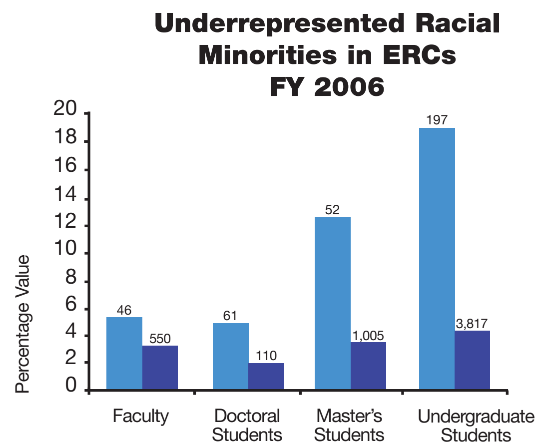
- Develop outreach connections with at least one Louis Stokes Alliance for Minority Participation (LSAMP) and an Alliances for Graduate Education and the Professoriate (AGEP) program

- Operate diversity-oriented REUs and pre-college programs involving teachers and students

*In compliance with federal law, no quotas or set-asides based on gender race, ethnicity, or disability are permitted. No numerical goals can be used, but quantification of impacts will be reported.*

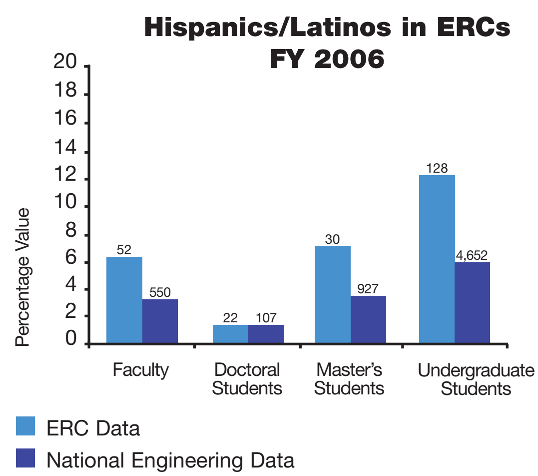



Minority groups traditionally underrepresented in engineering, including African Americans and American Indians, are better represented in ERCs than in other academic engineering programs nationwide (see middle chart to the right). For example, about 13% of those seeking a master's degree at an ERC in 2006, and 19% of the undergraduates, are in these population groups, compared to only 3% and 5% (respectively) nationwide. And nearly 6% of ERC faculty are in these underrepresented groups, compared to about 3% nationally.




Similarly, as shown in the bottom chart to the right, Hispanics* were better represented in the ERCs in 2006 than in academic engineering programs nationally—e.g., 6% of ERC faculty vs. 3% nationally; and 12% of all ERC undergraduates vs. 6% nationwide.

Several of the supplemental programs available to ERCs—such as REUs and RETs (see "Education and Outreach" section)—are aimed at helping to achieve greater diversity. The NSF-wide Louis Stokes Alliances for Minority Participation (LSAMP) program is focused on increasing the number of minority




* Hispanics are documented separately from racial minorities because they are an ethnic group consisting of several races.

Note: Figures represent 19 ERCs reporting in 2006 and do not include the 5 new ERCs, which were not yet reporting.

*In 2005 the ERC program launched a new diversity-oriented website called "Engineering Research Opportunities for Students," at http://www.diversity.erc-assoc.org/.*

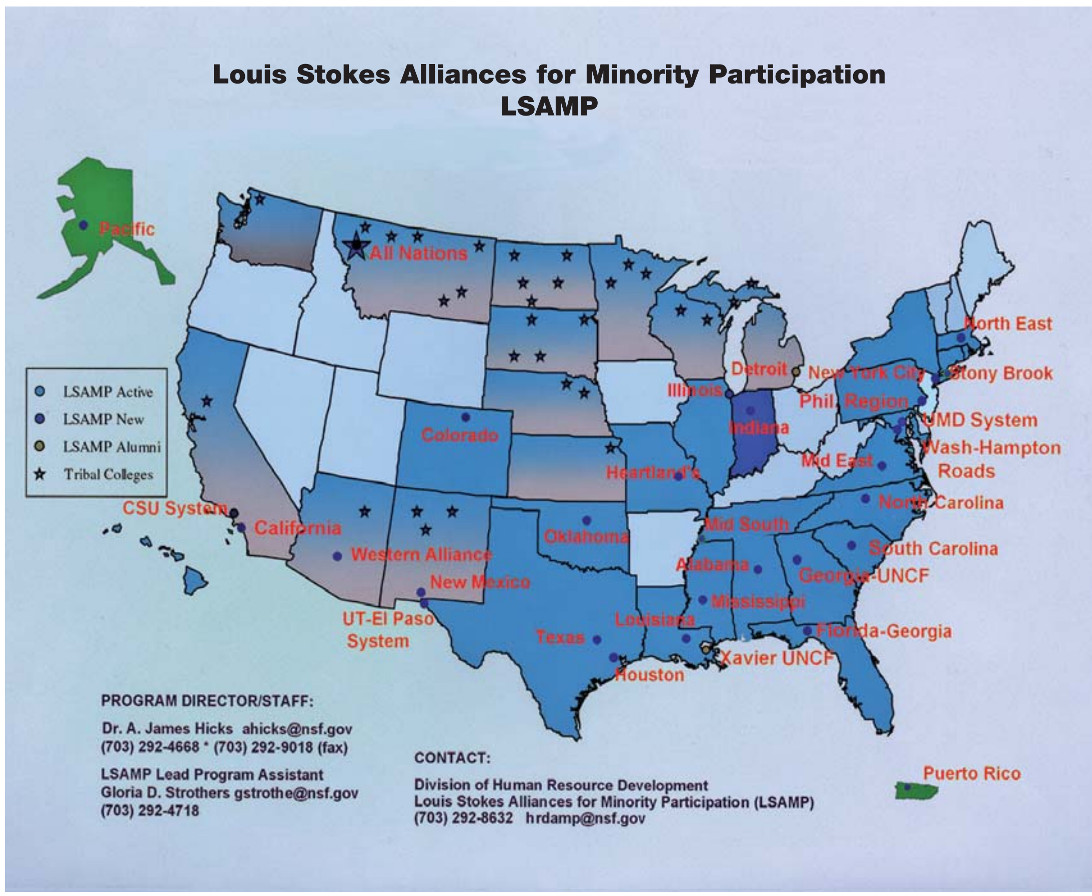

undergraduates in NSF-funded activities. It has active involvement by a number of ERCs, as shown in the LSAMP map on page 49.

As part of its strategic plan to increase participation in engineering by minorities and women, in 2005 the ERC program launched a new diversity-oriented website called "Engineering Research Opportunities for Students" (at http://www.diversity.erc-assoc.org/). The site, developed in conjunction with the managers of diversity-oriented programs at NSF, describes NSF programs available to minority engineering students and seeks to connect interested students with individual ERCS. To spread awareness of this site, information about it was sent to all awardees of LSAMP and other programs described in the site. In addition, ERC program staff attended LSAMP regional meetings where they presented information on the ERCs and the website to student attendees.

At the 2004 ERC Program Annual Meeting (held in November 2004, early in FY 2005), one full day was devoted to diversity issues, with plenary talks by the creators of nationwide programs aimed at recruiting

*ERCs are dedicated to broadening participation to include talented young people from all population groups.*

young women and minority students into engineering and science, as well as the directors of NSF diversity programs. Diversity again received significant attention in the 2005 and 2006 annual meetings (see “ERC Program Annual Meeting” section), with sessions devoted to “Strategies for Increasing Engineering Enrollments,” “Women in Engineering,” “Creating Effective Research and Education Partnerships with Other Universities,” and “Creating Diverse Multicultural Teams to Enhance the Educational Experience.” (Many such ERC partnerships with other universities are aimed at improving the research and education capabilities and infrastructure of predominantly minority-serving institutions.)

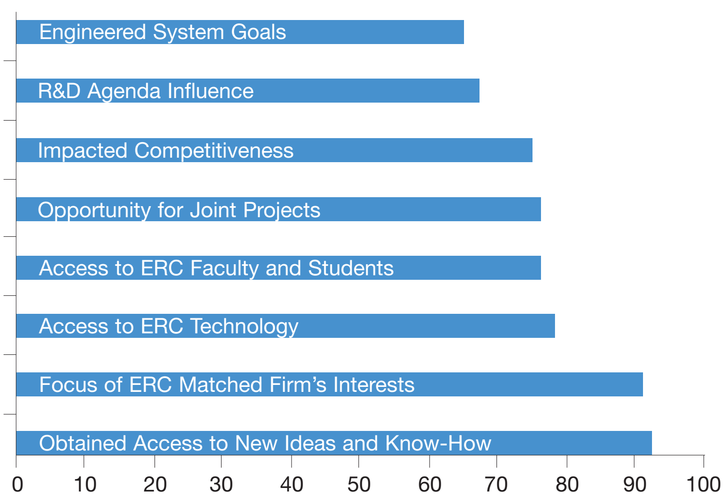


# Industrial Interaction

Since the first Engineering Research Centers were founded in 1985, these pioneering organizations have pushed the boundaries of knowledge across a broad spectrum of technology fields while transferring a continuous stream of cutting-edge technologies to their industrial partners.

One of the key features of every ERC is the mutually beneficial partnership it establishes with industry. The primary goals of this partnership—and the means by which each side of the partnership benefits—are a two-way exchange of information and knowledge, multi-faceted technology transfer, and the impact on students, both in terms of shaping their education through the contact with industry and through their employment and the impact that brings to the company. The table to the left lists the main benefits reported by industry for ERC membership.

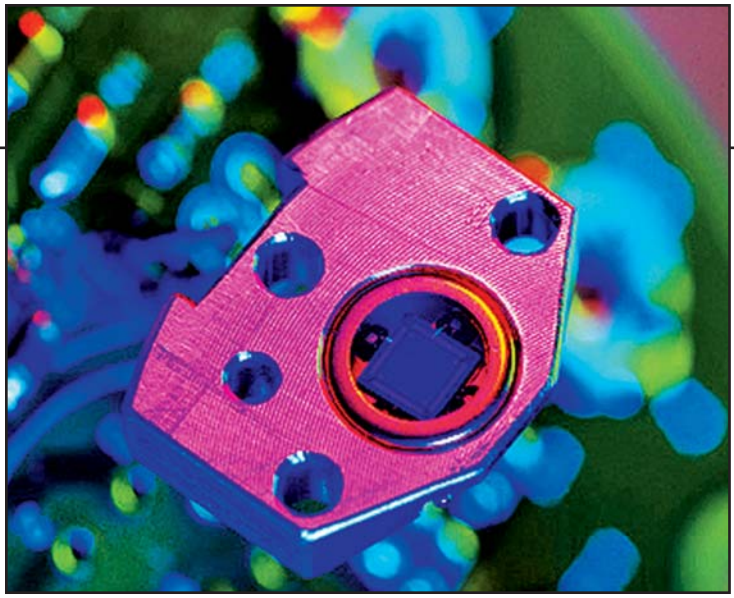
**ERCs Provide Significant Benefit to their Member Firms**




Source: SRI International, 2004

There is strong industrial involvement by industry partners in planning an ERC's research program and directions as well as the direction and shape of its education programs. This collaboration necessarily involves maintaining a careful balance between the longer-term strategic vision of the ERC and the nearer-term needs of industry. That continual interplay of needs and perspectives in turn helps keep the ERC grounded, vigorous, and relevant. The financial and other (e.g., in-kind equipment) support that an ERC's industrial members provide demonstrate their commitment to the ERC and help leverage NSF funding for the center.

In FY 2006 there were 268 total memberships encompassing 225 unique industrial members of the 19 ERCs,



for an average of 14 firms per center (see the table below). They provided a total of $16.18 million in direct support for the ERCs. This support comprised membership fees ranging from $5,000 to $100,000, depending on the center and its fee structure for different levels of membership. Sponsored project support totaled an additional $46 million. In addition to direct cash support and project sponsorship, industry also provided $2.7 million in in-kind support such as equipment, software, and research personnel on loan to the centers.

Some interesting trends notable in the table are: (1) a decline in the overall number of industrial members since 2001—a result of reduced R&D expenditures by U.S. companies and, in 2006, a temporary drop in the number of ERCs; (2) an increase in the proportion of small firms vs. large firms, a trend which may now be reversing; and (3) an increase in participation of foreign firms in an increasingly globalized economy.

**Industrial Participation at ERCs FY 2001-2006**

| | FY 2001 | FY 2002 | FY 2003 | FY 2004 | FY 2005 | FY 2006 |
|---|---|---|---|---|---|---|
| ERC Industrial Memberships | 542 | 375 | 357 | 345 | 331 | 268 |
| ERC Unique Member Firms | 505 | 290 | 294 | 299 | 288 | 225 |
| Number of ERCs | 20 | 18 | 19 | 22 | 22 | 19 |
| Average Number of Firms Per Center | 27 | 21 | 19 | 16 | 15 | 14 |
| Average Age of Centers in Years | 6 | 5 | 5 | 6 | 7 | 6 |
| Size of Member Firm: | | | | | | |
| Small | 24% | 31% | 34% | 34% | 31% | 28% |
| Medium | 11% | 9% | 9% | 9% | 10% | 11% |
| Large | 65% | 59% | 57% | 56% | 59% | 62% |
| Foreign Firms | 13% | 16% | 20% | 19% | 18% | 20% |

*Industrial competitiveness has always been a major driver of the ERC-industry partnership.*

**Intellectual Property Outputs, Innovation FY 1985-2006**

| | FY 1985-2005 41 ERCs | | FY 2006 19 ERCs | |
|---|---|---|---|---|
| | Total | Per Center | Total | Per Center |
| Inventions Disclosed | 1,325 | 32 | 108 | 6 |
| Patents Awarded | 488 | 12 | 40 | 2 |
| Patent Applications Filed | 955 | 23 | 90 | 5 |
| Licenses Issued | 1,840 | 45 | 50 | 3 |
| Spinoff Companies | 109 | 3 | 4 | |
| Spinoff Employees | 1,292 | 29 | 11 | 1 |

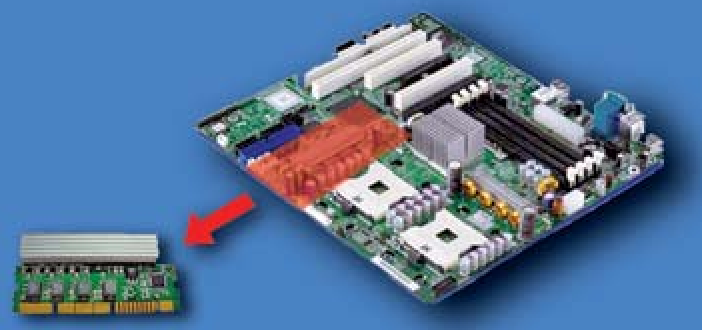
Industrial members generally enjoy early and even real-time access to ERC discoveries, inventions, and technologies. Thus, the intellectual property generated by the centers is a major incentive for industrial involvement. One important means of technology transfer for ERCs is the spinning off of new companies formed by ERC faculty, graduates, and students. The table above summarizes the various IP outputs of ERCs in 2006 and over the 22-year life of the program. Each ERC's Membership Agreement specifies in detail the types of access to center-developed IP according to level of membership, type of IP, and special funding arrangements.

## Innovations into Industrial Products and Processes

Advances made at the ERCs are often at the fundamental level but in many cases are then developed at the center to the point of precompetitive technology that can be transferred to industry. Very often the process of development is collaborative with industry researchers. The 43 successful ERCs established since 1985 have produced literally hundreds of technological innovations that have made their way into new industrial products and processes—not just within their member companies, but in many cases across entire industries.

A case in point is the Microsystems Packaging Research Center (PRC) at Georgia Tech. A total of 167 companies to date have taken parts of the System-on-a-Package (SOP) technology pioneered by the PRC and applied them to their automotive, computer, consumer, military, and wireless applications. The PRC has also built a number of test vehicles for

*Smaller, faster, and more efficient are a hallmark of many next-generation ERC microelectronics technologies.*



different companies focused on integrating different combinations of analog, digital, RF, optical, and sensor components in a single package. 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 follow SOP principles by designing and fabricating everything together.

Another example is the multiphase voltage regulator module (VRM) developed by the Center for Power Electronics Systems (CPES), at Virginia Tech. 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 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. CPES established a mini-consortium of companies with a keen interest in the development of VRMs for future generations of high-speed microprocessors. The Center then devised the multiphase buck converter as a VRM for the Intel processors. Today, every computer containing Intel microprocessors uses the multiphase VRM approach developed at CPES.

Among graduated centers, researchers at the Data Storage Systems Center at Carnegie Mellon University invented the NiAl underlayer that enables high-density media on glass substrates. The NiAl underlayer made possible small, high-capacity hard drives for laptops and MP3 players, including iPods. The market for these devices is in the hundreds of billions of dollars worldwide.

At another graduated center, Duke University's Emerging Cardiovascular Technologies ERC, two major research breakthroughs in antiarrhythmic systems—improved electrodes and biphasic waveforms—were transferred to the implantable defibrillator industry, where they led to both portable defibrillators and greatly improved implantable defibrillators. The market for these devices is over $10 billion annually.

## Start-ups

The interactive process of innovation at the ERCs has also led to many new companies being spun out of the centers as start-ups, many of which have become quite successful. Some examples of these startups follow.

■ *PerSeptive Biosystems, Inc.*

Noubar Afeyan, a Ph.D. graduate of MIT's Biotechnology Process Engineering Center, founded and built this company in 1991 to commercialize perfusion chromatography. Company revenues grew from $1 million in 1991 to around $100 million in 1997. PerSeptive merged with PE Corporation in 1998, in a transaction valued at $360 million. Later, while a Senior Vice President at PE Corp., Afeyan initiated and managed the creation of Celera Genomics, a subsidiary of PE Corp. Celera recently completed the sequencing of the human genome.

■ *RF Solutions*

RF Solutions was founded in 1998 by four Packaging Research Center students and Georgia Tech Professor Joy Laskar to provide integrated circuit and package design services for wireless communications markets. The company was acquired by Anadigics in 2002, which established it as Anadigics' wireless local area networks (WLAN) Center of Excellence. That Center has focused on power amplifier products for notebook and handheld applications. Presently, the Anadigics WLAN power amplifiers are the best-selling in the world, with shipments totaling over 100 million units, and are responsible for approximately 25% of Anadigics revenue.

■ *DigitalPersona*

DigitalPersona, founded by two former CNSE undergraduate students (1996), has become a leader in biometric password management. This is a completely new approach to password management on PCs and corporate information systems. The company's tech-

*ERCs spin off discoveries, innovations, graduates, and companies.*


nology and design are used in Microsoft's Fingerprint Reader devices and many other products. DP markets its own fingerprint readers directly to consumers. Currently there are about 30 million users of this technology worldwide.

■ *Audyssey Laboratories*

MultEQ™ software automatically corrects frequency response distortions to improve and equalize the audio experience for all listeners at different locations in a listening area. Integrated Media Systems Center spinoff company Audyssey Laboratories (founded 2002) has licensed MultEQ™ and other technologies to several leading consumer electronics manufacturers in the US and Japan for use in home and car electronics products. By December 2006, one million products had been shipped with Audyssey technology.

■ *Discera*

Founded in 2001 by a researcher at the University of Michigan's Wireless Integrated MicroSystems ERC, Discera'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.

Discera is selling product 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 will represent Discera and distribute its products to Japanese customers focusing on wireless communication markets. Discera products are expected to dominate in the $3.5 billion worldwide timing market.


# Academic Partnerships: A Global Network

Close collaboration among multiple university partners is one of the many ways in which ERCs have redefined the concept of an academic research center, serving as a model for the development of other Centers programs in the U.S. and around the world.

Since 1998, all newly funded ERCs have been multi-institutional. That is, they have in addition to the lead institution at least one core partner (some have four or more). They also have active affiliations with outreach institutions, including female and minority-serving institutions and NSF diversity awardees (LSAMPs, etc.). The core partners participate as full partners in pursuing the strategic goals of the center in research, education, and technology transfer. Although they may be geographically quite dispersed, the collaboration is continuous and multifaceted, including shared curriculum and graduation requirements, regular student and faculty exchanges, joint meetings, etc. Interactions with outreach institutions can involve research collaborations, hosting students, and joint projects of various kinds.

**ERC Participating Institutions 2006**

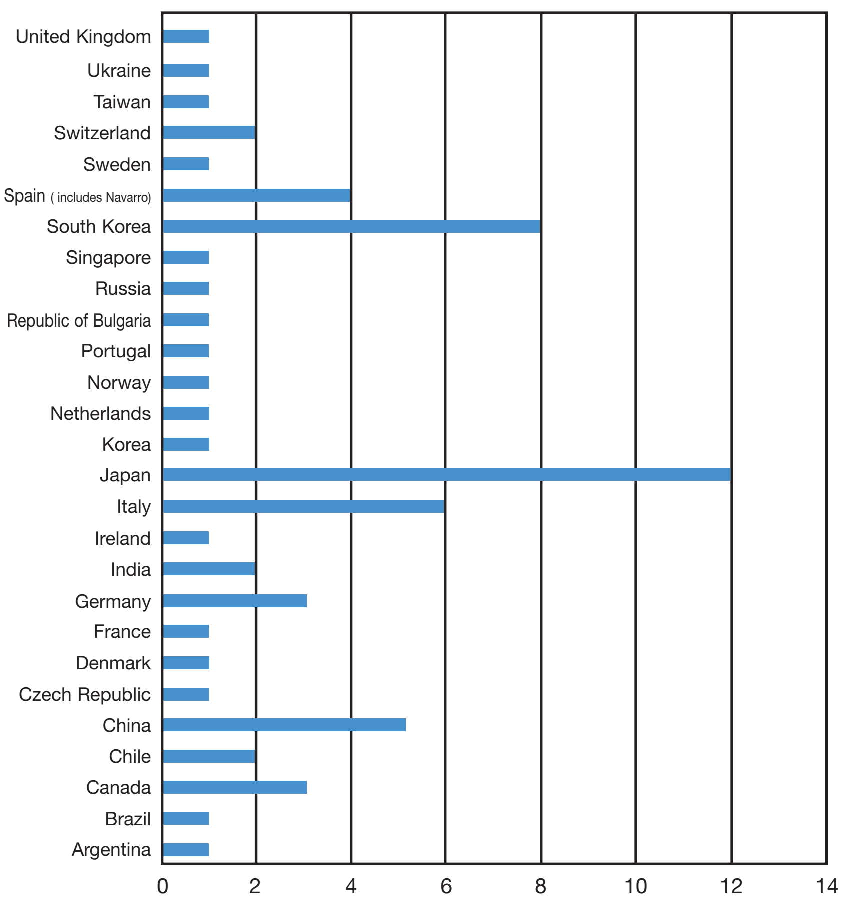
| Organization Type | Total | Underrepresented Populations | |
|---|---|---|---|
| | | Female Serving | Minority Serving |
| Lead Institutions | 19 | 0 | 0 |
| Core Partners | 41 | 0 | 3 |
| Outreach Institutions | 201 | 5 | 29 |
| **Total** | **261** | **5** | **32** |

The table to the left shows the number of institutions participating in the 19 ERCs reporting in 2006.

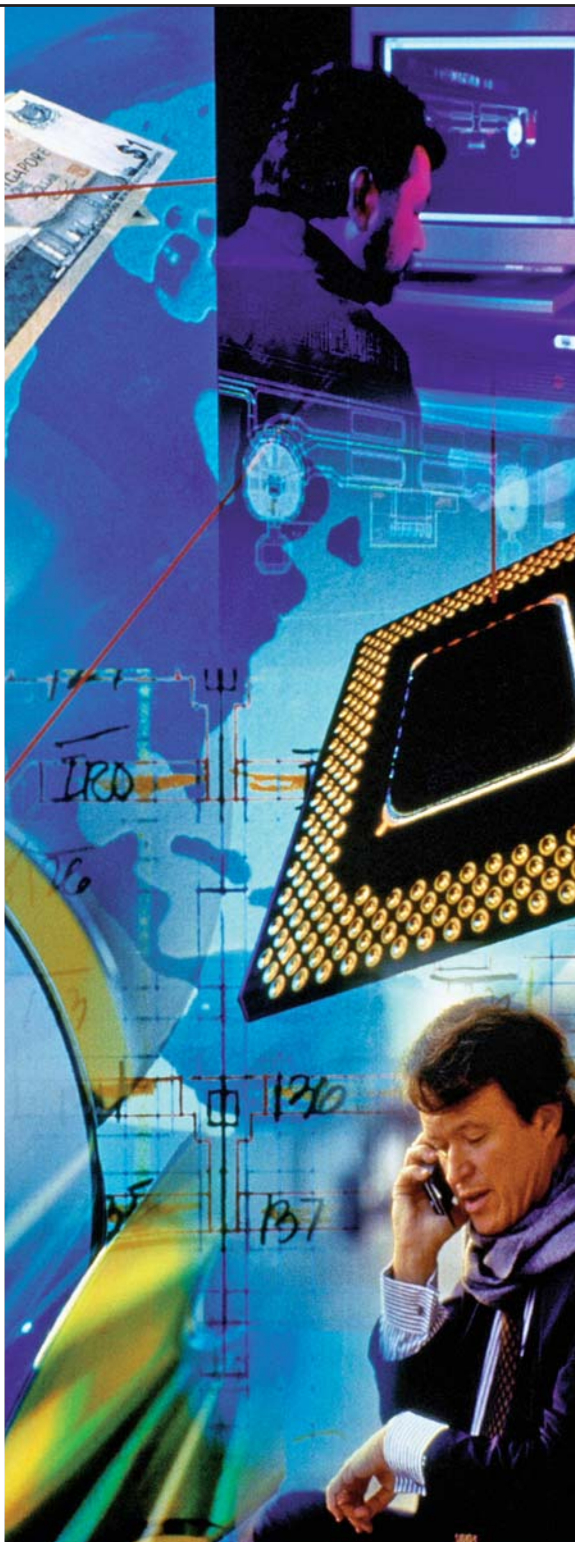
In recent years there has been an increasing trend for ERCs to collaborate in both research and education with foreign universities and research facilities. Often, the research collaboration takes the form of cooperation in a highly defined area in which the foreign institution has recognized expertise. Or, as in one case, at the foreign institution a testbed might be set up that is useful for extensive testing of concepts developed by the core partners, with students and researchers going in both directions.

As of the end of 2006, the ERC outreach institutions included a total of 59 foreign universities in 26 different countries. The chart on page 57 shows the distribution of these collaborating institutions.

## Foreign Universities Collaborating with ERCs by Country FY 2006

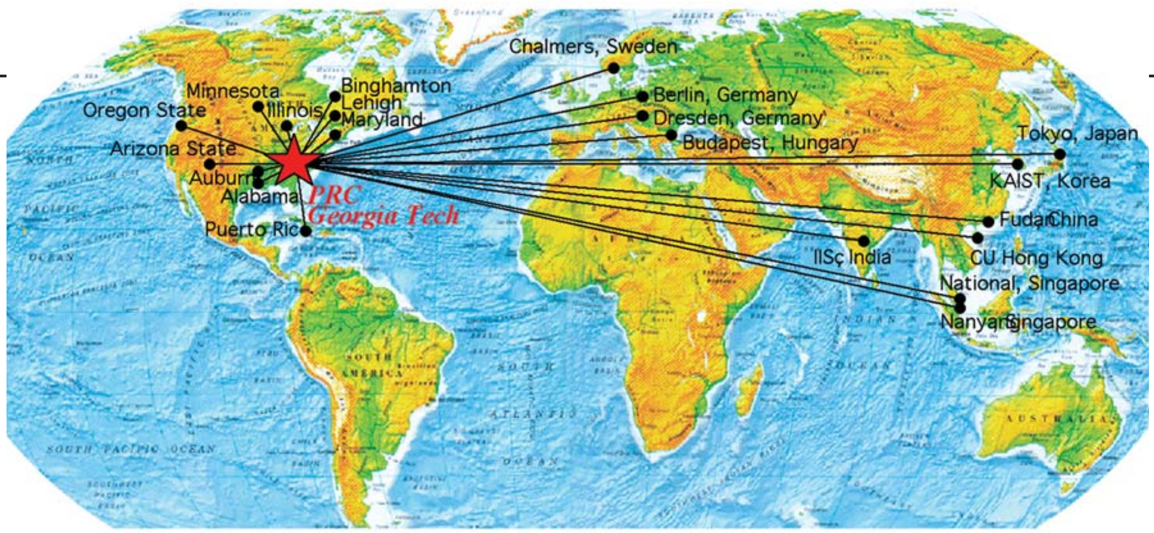



* Includes FY 2005 data for University of Arizona CEBSM.



**Reconfigurable Manufacturing Systems ERC**
**Global Academic Collaborations and Impact Areas**

**Packaging Research Center at Georgia Tech**
**Global Academic Collaborations and Impact Areas**




- Textbooks
- Collaborative Research
- Faculty Sabbatical
- Distance Learning
- Unique Equipment
- Industry Interaction
- Curriculum Development
- Leverage Technical Strengths
- Test Vehicles and Prototypes
- Outreach and Diversity
- Pre-college Programs
- Student Exchanges

The global connectivity of some ERCs is far-flung and extensive. The figure on page 58 shows the international involvements of the University of Michigan's Reconfigurable Manufacturing Center (RMS). Similarly, the figure above shows the global connectivity of Georgia Tech's Packaging Research Center (PRC).

NSF's plans for the future of the ERC program are defined in terms of "Generation 3" ERCs. An important component of this new ERC is that they: "Prepare ERC graduates to function in a global world where competence in engineering and innovation are widely distributed."

The expectation is that:

- Some ERCs will have foreign core partners whose faculty and students are integrated into the ERC's research and education programs (foreign government funds must support foreign faculty).

- All ERCs will provide experiences where students can gain first-hand knowledge of engineering practice outside the US.

See the "ERC Program Management" section for further description of Generation 3 ERCs.

# Center Key Events

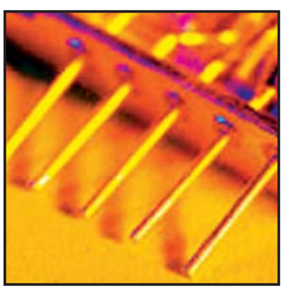
With five ERCs graduating from the program in 2005 and early 2006, and five new centers added in 2006, this program continues to evolve and grow.

**New ERCs: The Class of 2006**

In the summer of 2006, a lengthy process of selection culminated in the establishment of five new ERCs.

■ Synthetic Biology Engineering Research Center (SynBERC)

SynBERC will focus on synthetic biology, i.e., fabricating new biological components and assembling them into integrated, miniature devices and systems such as microbial drug factories or tools for seeking out and destroying cancerous tumors, pollutants or air-borne warfare agents. Center researchers envision devices that incorporate "off-the-shelf" biological parts—whether enzymes, cells or even genetic circuits—with standardized connections that can even be integrated into non-biological systems.



This ERC's vision is to push synthetic biology engineering to the next level, away from time consuming, one-of-a-kind development efforts and to the rapid creation of new products from standardized components. Success in this endeavor will impact the biotechnology, pharmaceutical, genetics, and chemical fields, potentially leading to an entirely new landscape of diagnostic, therapeutic, and synthetic chemical industries.

SynBERC is based at the University of California at Berkeley, in partnership with Harvard University, the Massachusetts Institute of Technology, Prairie View A&M University, and the University of California, San Francisco (UCSF). The ERC will also partner with the University of California Louis Stokes Alliance for Minority Participation (LSAMP) and the California Alliances for Graduate Education and the Professoriate (AGEP) at Berkeley and UCSF to increase involvement of under-represented minority students in the field.

The Center has industry partners that include 12 firms committed to membership and representing suppliers of genetic tools and custom DNA components, pharmaceutical and chemical firms, and firms interested in developing simulation software and computational tools. Venture capital firms will advise SynBERC on start-up business opportunities.

■ Quality of Life Technology Engineering Research Center (QoLT)

QoLT will develop a range of technologies that will allow people with limited mobility or other physical and mental restrictions to live more independent and productive lives. Working in design partnerships with

older adults, people with disabilities, and their care providers, the ERC will target new technologies that advance machine perception, intelligent robotics, and miniaturization to craft devices ranging from wearable health monitors for older people to novel "intelligent" home systems that allow people with restrictive disabilities to operate household appliances or drive a car. The center will also develop modifications, such as navigational aids, for wheelchairs and other existing technologies. The ERC includes a strong partnership between engineers and computer scientists, social and cognitive scientists, and rehabilitation practitioners to help ensure that the technologies will meet user needs.

QoLT is based at Carnegie Mellon University with the University of Pittsburgh (Pitt) as its core partner. Through this partnership, the center engages faculty from Carnegie Mellon's Robotics Institute and the H. John Heinz III School of Public Policy & Management, along with the Pitt Center of Assistive Technology in the Department of Rehabilitation Science and Technology, Pitt's Human Engineering Research Laboratories at Highland Drive VA Medical Center, the University of Pittsburgh Medical Center, and several residential and institutional facilities for older adults and people with disabilities. To increase the diversity of engineers and scientists engaged in this field, the ERC will partner with the Florida/Georgia LSAMP, Chatham College, Howard University, and Lincoln University.

The Center counts among its industry partners 18 companies representing various fields including robotics, medical devices, consumer electronics, information technology, and assistive technology.

■ Engineering Research Center for Compact and Efficient Fluid Power (CEFP)

CEFP will develop compact, low cost, next-generation fluid-powered devices—systems that use pressurized liquids or gases to transmit power. Fluid power is already a multi-billion-dollar global industry with uses in aerospace, agriculture, construction, health care, manufacturing, mining, and transportation. CEFP researchers intend to develop a range of new technologies, such as hybrid vehicles with efficient fluid power components and wearable fluid-power assisted devices that run for extended periods without external energy sources—ideal mobility aids for people with disabilities or power sources for compact machines such as rescue robots.

CEFP is based at the University of Minnesota in partnership with the Georgia Institute of Technology, the University of Illinois at Urbana-Champaign, Purdue University, and Vanderbilt University. Outreach universities include the Milwaukee School of Engineering and North Carolina A&T State University (NCAT). Other outreach institutions include the National Fluid Power Association, Project Lead the Way, and the Science Museum of Minnesota. The ERC will form partnerships with the LSAMP headquartered at NCAT, the Tennessee LSAMP headquartered at Tennessee State University; and the AGEP headquartered at the Georgia Institute of Technology.

With help from the National Fluid Power Association, more than 50 partner companies have agreed to provide $3 million in support for the new Center.

■ Mid-Infrared Technologies for Health and the Environment (MIRTHE)

MIRTHE researchers will develop technologies that use mid-infrared quantum cascade lasers as the backbone for a wide range of next-generation air-monitoring sensors. Mid-infrared light reveals the presence of key gas molecules—such as carbon dioxide, ammonia, methane, and benzene—to specialized sensors. Such sensors have the potential to be accurate, extremely compact, affordable, and easy for


non-specialists to operate. In widespread use, such systems could revolutionize how people perceive the air around them, revealing toxins released by industrial processes, monitoring greenhouse gases, and even alerting governments to possible chemical attack. The systems would also introduce a new class of affordable breath analyzers for routine diagnostics by primary care physicians. Doctors could monitor breath for byproducts of protein metabolism, indicators of kidney dysfunction, liver dysfunction, cancer detection, or stress.

MIRTHE is based at Princeton University in partnership with Johns Hopkins University, the University of Maryland–Baltimore County (UMBC), Rice University, Texas A&M University, and the City College of New York.

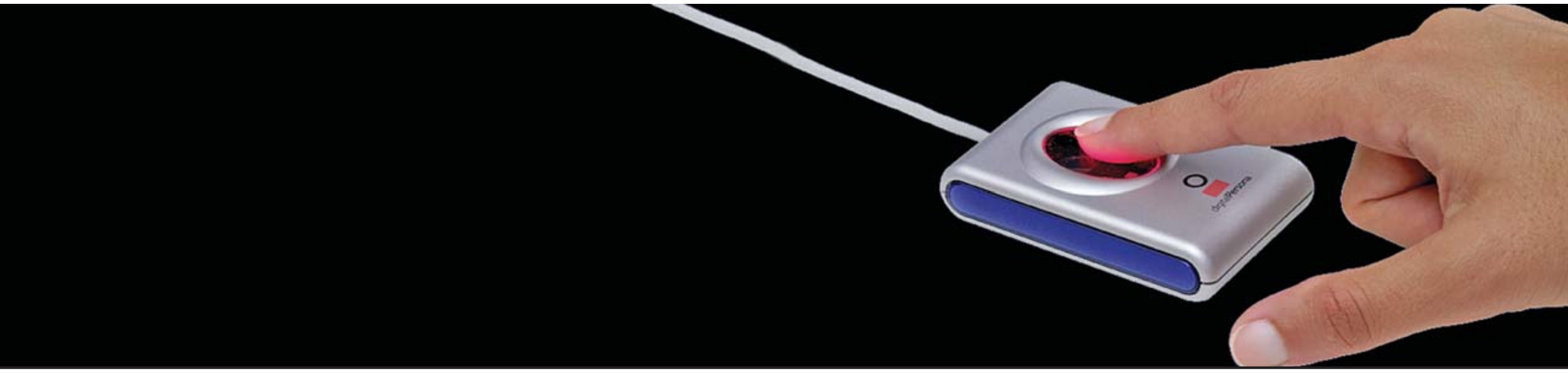
The center is collaborating with dozens of industrial partners and several educational outreach partners, including the Meyerhoff Scholars Program—a competitive program at UMBC that challenges gifted, underrepresented minority students to become leading research scientists and engineers—the UMBC and Rice University AGEPs, LSAMPs, Graduate Teaching Fellows in K-12 Education, and others.

■ Engineering Research Center for Structured Organic Particulate Systems (C-SOPS)

C-SOPS will study the nature of finely ground granular materials and other substances that form the core of drug tablets, processed foods, agricultural chemicals, and other "composite organic" products. In addition to improving the quality and consistency of such materials, the Center will develop more consistent and cost-effective manufacturing techniques to replace methods based largely on trial and error.

C-SOPS is based at Rutgers University in partnership with the New Jersey Institute of Technology, Purdue University, and the University of Puerto Rico, Mayaguez. Outreach partners include the City University of New York (CUNY) AGEP; the Midwest Crossroads AGEP; the University of Puerto Rico AGEP; and the Indiana, Puerto Rico, and CUNY/NYC LSAMPs. Precollege outreach programs include high schools near the partner universities in New Jersey, Indiana, and Puerto Rico and a vocational-technical high school in Puerto Rico.

Industry partners include 28 companies that are providing a total of $2.5 million in research funding in the first year. They include pharmaceutical and food manufacturers along with suppliers of manufacturing and analytical equipment.



## Graduating Centers

Five ERCs completed their eleven-year term of ERC Program support in 2005 and 2006:

- Center for Neuromorphic Systems Engineering (CNSE), at CalTech
- Packaging Research Center (PRC) at Georgia Tech
- Particle Engineering Research Center (PERC) at the University of Florida
- Biotechnology Process Engineering Center (BPEC), at MIT
- Center for Environmentally Benign Semiconductor Manufacturing (CEBSM), at the University of Arizona

### ■ Center for Neuromorphic Systems Engineering

Today, most machines need a human “master” to tell them what to do via knobs, sliders, keyboards, and pointing devices. But researchers at the Center for Neuromorphic Systems Engineering have been envisioning a future where machines sense, interact with, learn from, and adapt to their environment with the same ease as living creatures. The hope is that this generation of smarter machines will greatly improve consumer products, human/computer interaction, healthcare, manufacturing, and telecommunications.

During its tenure as an ERC, CNSE has followed nature’s lead by developing special-purpose systems for specific sensory processing tasks. When these special-purpose sensors and processing electronics are coupled with biologically inspired learning algorithms and appropriate computational architectures, the resulting integrated sensory system can offer robustness in response to environmental variations and useful performance over a very wide range of input magnitude. The goal is to devise technologies and systems that, someday, will allow machines to communicate meaningfully with people.

For example, a team of Caltech electrical engineers has created a “phased-array transceiver” — a silicon chip, smaller than a penny, with radar and communication capabilities that could help vehicles avoid obstacles. It works much like a conventional radar system, but takes less space, costs less, and does not require the rapidly turning antenna.

A chip attached to the front of a car could be linked to an interior screen displaying everything in the car’s path. The car could then be programmed to avoid

*Microsoft's new fingerprint readers rely on fingerprint-identification technology developed by a CNSE start-up company, DigitalPersona.*

obstacles or to stop before crashing — all without human intervention. The phased-array transceiver chip could also be used in military applications to monitor an area in place of human patrols. Operating at 24GHz (meaning it cycles 24 billion times every second), the chip could be used as a wireless alternative to optical fibers for clear, high-speed communication.

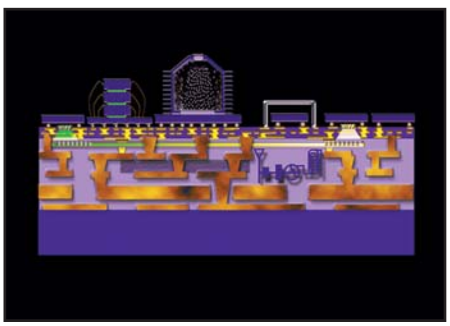
Spinoff companies and startups are an important means of dissemination for CNSE-developed technologies. Microsoft is now shipping products that contain fingerprint-identification technology developed by a CNSE start-up company, DigitalPersona. The new Microsoft products introduce biometric password management using software which includes a novel engine that makes fingerprint recognition fast and reliable. These products aim to reduce "password fatigue" by making it more convenient to open password-protected pages while continuing to insure privacy and security. The fingerprint reader is designed to be intuitive and reliable. It is expected that this technology will soon become ubiquitous wherever people use computers.

## ■ Packaging Research Center

"Packaging" of electronic systems requires integration of active and passive components on system boards. The active components typically are integrated circuits (ICs) for computing, communication, and sensing functions, while the passive components that form the circuits needed to achieve these functions typically are such things as capacitors, resistors, inductors, filters, and switches. The leading-edge active components currently are at nanoscale, but the passives typically are at microscale. The system boards that interconnect these components to form systems such as cell phones are at milliscale—a million times bigger than the active ICs. Consequently, current systems are bulky in size. In addition, the current systems are discrete systems: i.e., digital systems performing computations, communications systems providing voice-based functions, and so on. The result is that consumers own multiple electronic systems—computers, cell phones, audio and video systems, etc. The primary mission of the Packaging Research Center (PRC) at Georgia Tech has been to pioneer new ways to enable digital convergence of all types of consumer electronic products into portable and personal systems.

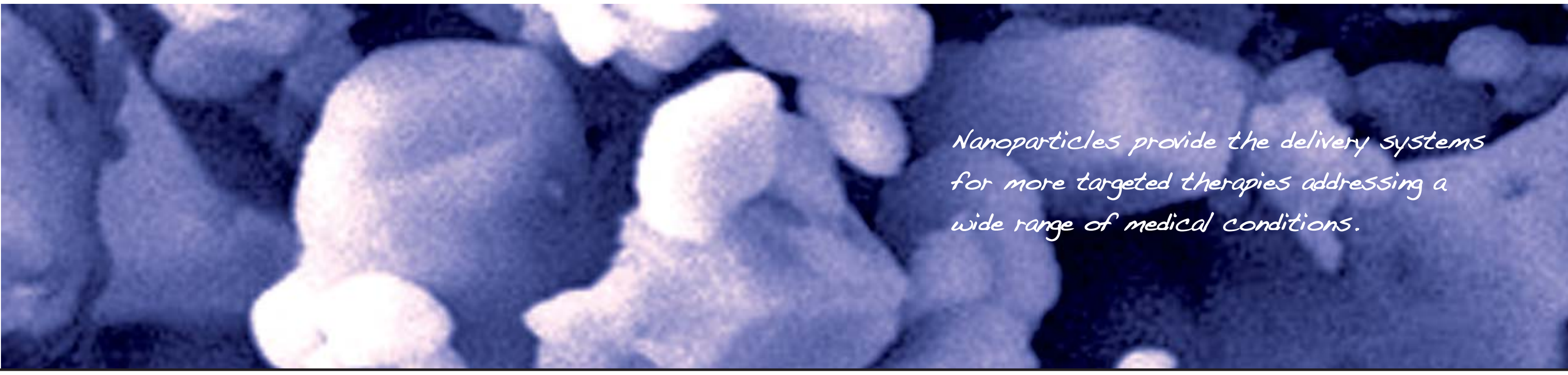
*The PRC has pioneered the "System-on-a-Package" approach to achieving digital convergence of electronic devices through component or system integration.*

To achieve this convergence, the PRC's technical vision involves integrating all of the components as embedded thin-film components at nano to microscale, either into active ICs or as miniaturized packages into a single-system package. The Center terms this technology "System-on-a-Package" (SOP). The SOP concept is analogous to the earlier integrated circuit revolution leading to a system-on-a-chip by means of transistor integration, but now it is component integration or system integration through SOP to achieve digital convergence.



During its 11 years as an ERC, the PRC and its industry partners jointly designed and implemented a strategy to cooperatively develop the new SOP technologies, educate the next generation of packaging engineers, and transfer both technologies and graduates to industry to strengthen its competitiveness. This partnership resulted in hundreds of industrial internships and well over 300 of the Center's graduates hired by its industrial partners. Industrial practitioners routinely gave lectures in the classroom and participated on thesis committees. The PRC hosted over 60 visiting industry engineers on campus, documented numerous examples of technology transfer, and disclosed nearly 200 inventions. By developing a portfolio of critical SOP technologies and graduating over 500 skilled SOP engineers, the PRC has enabled an SOP-based industry to emerge.

The PRC also impacted local economic development by creating spin-off companies, attracting spin-in companies, and assisting local start-up companies in incubating nascent technologies. A study prepared by SRI International for the Georgia Research Alliance estimates that the total quantifiable contribution of the PRC to the Georgia economy over 10 years has been $351 million, more than a 10-to-1 return on the investments by both NSF and the State of Georgia.




■ Particle Engineering Research Center
Particles are used in a myriad of ways in modern manufacturing, as both tool and product. Particle technology deals with the production, characterization, modification, handling, and utilization of organic and inorganic powders as well as bioparticles, in both dry and wet conditions. Particulate systems are a core technology in many industries including advanced materials, chemical, energy, environmental, mineral, agricultural, pharmaceutical, biotechnology, and food processing.

The aim of the Particle Engineering Research Center (PERC), at the University of Florida, has been to develop innovative particulate-based systems for next-generation processes and devices that improve the nation's industrial strength, environmental quality, and public health, while producing top-flight engineers and scientists in the vital field of Particle Science and Technology (PS&T). Experts and advanced-level students in the field are scattered all around the world, and no single institution has expertise in all of the multidisciplinary areas that comprise PS&T.

To bring these experts together, the PERC established the Particle Science Summer School in Winter (SSIW). The SSIW program is an intensive, week-long program for graduate students that provides advanced training in PS&T topics in an international forum, taught by world-class experts from both academia and industry. The students come from around the country and abroad. In addition to training the next generation of PS&T researchers, the program gives these students as well as the PERC's students an opportunity to begin to network and collaborate across continents. This is just one example of the innovative education programs, integrating research into education, that the PERC has offered.

During its 11-year life as an ERC, the Center has also made numerous advances in PS&T. An example is the work on "smart nanotubes" for selective biomolecule delivery to living cells. Most drugs used to treat life-


threatening human maladies such as cancer, heart disease, and AIDS cause serious side effects because, in most cases, the drugs are administered to the whole body, even though they need to act on only a small part of it. Researchers at PERC developed a major new alternative drug transport technology consisting of an assembly of mono-dispersed tubular nano-particles with and without "chemical sensing" nanocaps at the ends of the tubes. Specific targeting technology is incorporated into the structural platform. Simply stated, smart nanotubes developed at the PERC will in the future be able to deliver drugs to only the target cells (diseased cells), thereby greatly reducing the dose a patient would need to take and providing targeted and more effective treatment.

Using center-developed advances in nanometer-scale particle delivery, Nanotherapeutics, a PERC spinoff company, adapted the technologies and has applied them to the development of new pharmaceutical and over-the-counter products featuring once-a-day delivery systems. Examples of benefits include improved breathing for asthmatic patients for the entire day; relief from a migraine headache in minutes instead of hours; and taking one-hundredth of the normal dose of an antibiotic for a local infection, with less nausea.

Nanoparticles provide the delivery systems for more targeted therapies addressing a wide range of medical conditions.

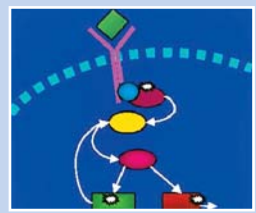
### ■ Biotechnology Process Engineering Center

The Biotechnology Process Engineering Center at MIT was one of the first six ERCs established by NSF in 1985. BPEC was the only ERC ever to recompete successfully for a new award and survive subsequent reviews to complete the second award period. The Center graduates from the ERC program leaving a powerful legacy of achievement in bioengineering that includes graduates spread throughout academe and industry.

BPEC's mission has been to foster cross-disciplinary, systems-driven research and education that fuses engineering with molecular cell biology. Its primary focus has been on pharmaceutical applications of biotech-

**Evolution of BPEC Research**

As biological information and complexity increases, engineering approaches are needed – and can have crucial impact – earlier in the drug development process.



Engineering, analysis, design, synthesis

Target identification ▶ Target validation ▶ Molecular/cell therapy identification ▶ Molecular/cell therapy identification ▶ Production

BEPC I - proteins

BEPC II - genes and stem cells

BEPC III - new tools for understanding human disease mechanisms and for developing therapies

nology. Throughout the 20 years of its existence, the Center found that ever-increasing biological knowledge and complexity have pushed the opportunities for applying engineering ever-earlier in the drug development process (see the figure to the right).

- BPEC I (1985–1997) focused on therapeutic protein biotechnology (using cell culture bioprocessing)
- BPEC II (1998–2003) focused on therapeutic gene biotechnology (using selective gene delivery)
- BPEC III (2003–future) focuses on developing enabling technologies for biotech and pharmaceutical industry drug discovery and development.

Advances in mammalian cell bioprocess technology and protein therapeutics made by BPEC—such as the BioDesigner for bioprocess simulation, algorithms for scientific design of cell growth media, and methodologies for characterizing protein quality—have enabled the development of a wide range of new pharmaceuticals over the last 20 years. BPEC alumni—occupying 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—have accounted directly for many of these pharmaceutical developments by applying BPEC-developed knowledge and technologies in their companies.

BPEC alumni at Genentech, for instance, played key roles in bringing new cancer therapies to market. These new monoclonal antibodies, named RituxanR, HerceptinR, and AvastinR, kill cancer cells without causing many of the deleterious side effects of traditional chemotherapy. BPEC alumni helped develop new high-titer, fed-batch manufacturing processes for these drugs, and then helped design and build some of the largest and most automated manufacturing plants of their type in the world. BPEC alumni at Merck, as another example, have played key roles in the global battle against AIDS. In the early 1990s, they manufactured parts of the AIDS virus as drug screening targets, found a promising candidate molecule, developed a new manufacturing process to synthesize the molecule, and then played key roles in the design and start-up of a new manufacturing facility. The new drug, CrixivanR, when combined with older AIDS drugs, can clear the AIDS virus from the bloodstream of many victims and allow them to lead productive lives. Other BPEC graduates have founded biotechnology start-up companies such as PerSeptive Biosystems, Concordance Biosystems, and Intelligen. In all, 64 companies in industries ranging from biotechnology to pharmaceutical to chemical processing have been members of the Center.

Based largely on the success of BPEC, and through the energetic advocacy of the Center's leadership, MIT in 1998 established a new Biological Engineering Division. Biological Engineering (BE) is a new discipline at the intersection of biology and engineering, with applications not only in human health care but also in industries such as materials, manufacturing, defense, chemicals, and agriculture. The new academic unit led to the creation in 2005 of a Biological Engineering undergraduate degree program, the first new course of study established at MIT in 29 years. BPEC's record is a powerful story of accomplishment that continues to be written.

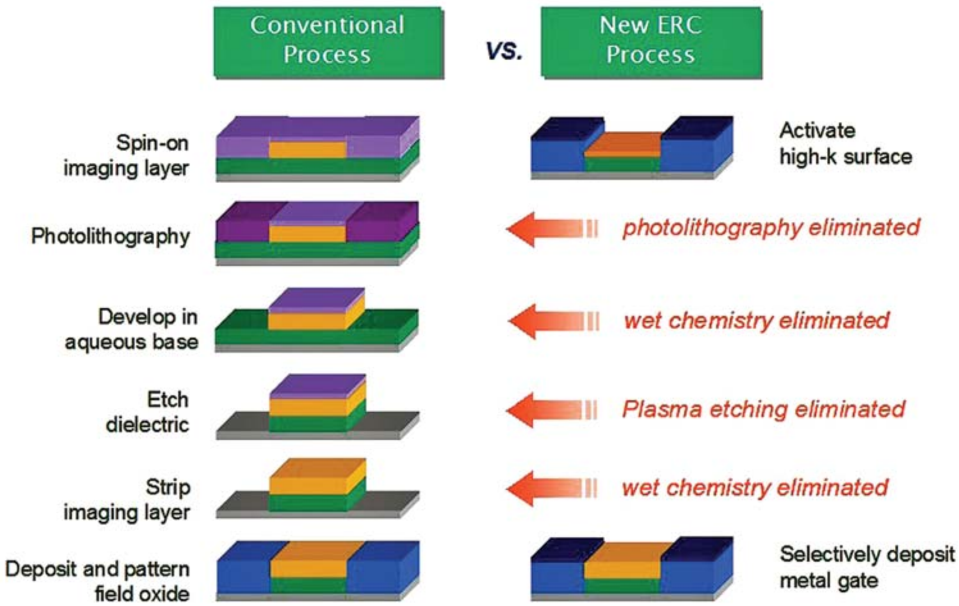

■ ERC for Environmentally Benign Semiconductor Manufacturing

The making of semiconductors requires large amounts of water, energy, and chemicals. The use of these resources, the safe handling of toxic chemicals, and the safe treatment and disposal of the complex waste that is generated all have major environmental implications, if not controlled. The semiconductor industry has taken steps to reduce the environmental, safety, and health (ESH) impacts of its operations and develop environmentally benign alternatives. But this is an industry in which processes and products change rapidly. Consequently, it is difficult to foresee and include ESH considerations in a timely manner in the design of new products and processes. The challenge lies in developing ESH-friendly technology early enough to integrate it into the design of tomorrow's chip manufacturing processes and tools.

Established in 1996, the CEBSM was one of the first multi-university ERCs, led by the University of Arizona with partners including MIT, Stanford, UC-Berkeley, Cornell, and Purdue University. Its overall aim has been to devise the science, technology, and educational methods that will lead to future semiconductor manufacturing facilities that require minimal consumables (water, energy, acids, solvents, and gases) while producing minimal emissions of environmentally harmful, unsafe, and unhealthy waste materials. The Center was unique among ERCs in being jointly funded by another entity, the Semiconductor Research Corporation (SRC). In all, 57 companies and a number of government agencies are or have been members of the Center, ensuring rapid and effective transfer of Center-developed technologies throughout the industry.

Mindful that potentially reduced profits will inhibit the interest of semiconductor manufacturers in adopting ESH-friendly technologies, the Center strove to achieve environmental gains while at the same time reducing costs and improving process-related quality and performance. One approach was to aim toward future IC fabrication facilities whose technologies and processes will lower both water and energy use significantly below current levels.  For example, along with its partners, CEBSM set up a unique physical and simulation testbed facility that has allowed researchers to devise improved water conservation and recycling

**Environmentally Benign Chip Fabrication**




tools and techniques that have applications for a broad array of industries. Some of the techniques developed at the facility have already been transferred to industry and are in use.

Another example: Currently, in the manufacturing of semiconductor devices, various materials are deposited in layers and then almost completely removed after patterning, in what is called "subtractive processing." Research at the CEBSM has laid the groundwork for a more efficient "additive processing" approach that promises to improve performance while lessening materials and energy use and waste. Researchers made a major breakthrough by developing a new selective deposition process in which metals are added directly to the substrate to form the gates. They also developed new photo-imageable materials. Together, these new approaches eliminate steps in the chip manufacturing process that waste energy, materials, and water (see figure above). Thus, the new process is much more environmentally friendly and less expensive than the process it replaces. Five of the Center's member companies are assisting in the transfer of this technology. A CEBSM faculty member, along with two CEBSM graduates, founded startup firm GVD Corp. to commercializing the technology.

Educating engineers who understand how to integrate ESH into IC manufacturing process design and development, reaching out to attract talented new students from across society, and providing continuing education for the semiconductor industry—these have been hallmarks of the CEBSM's education program. Recognizing that precollege outreach is a high-leverage way to increase the numbers of young people who study engineering, the Center launched a Teachers Institute in 1997 to "teach the teachers," and secondarily, to organize outreach programs to precollege students in remote areas. At the Institute, teachers spend their summer months working with CEBSM researchers and preparing innovative curricula in environmental areas. They work together to use the resources of the ERC and industry to develop new lessons and materials for their own classrooms. Through the course of eight summers, 134 precollege teachers from Arizona and California participated in the Institute's outreach programs, developing nearly 200 new lab and classroom exercises as a result of their summer research, and reaching thousands of students, many of them Hispanics and Native Americans in small rural communities. In its education programs, as in its research programs and technology transfer activities, the CEBSM cast a wide net across many partners and participants, ensuring that its influence and the benefits of its work have had the maximum impact.

**Gordon Foundation Gift to CenSSIS/Northeastern**

In August 2006, Northeastern University announced its receipt of a $20 million gift from The Gordon Foundation, established by engineering innovator and philanthropist Bernard M. Gordon and his wife. The gift is the largest single donation in the university's history. It will support the Center for Subsurface Sensing and Imaging Systems (CenSSIS) and establish an innovative model for educating engineering leaders. The Gordon gift will enable CenSSIS to continue its operations after graduation from ERC funding in 2010, and to evolve from an academic research center into an R&D center focused on converting research into new products for commercial and governmental markets. The gift will also establish within CenSSIS the Gordon Engineering Leadership Program, an intensive one-year graduate program aimed at building an elite corps of engineering professionals. The program will begin in September 2007. In recognition of this important gift, CenSSIS was renamed the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems.

**Center Leadership Changes**

Executive management positions in the existing ERCs saw little change in 2005 and 2006. At USC's Integrated Media Systems Center (IMSC), Mr. Adam Clayton Powell III took over as Center Director during 2005. Mr. Powell, a longtime champion of new media who helped start and then ran Internet and technology programs for the Freedom Forum (formerly the Gannett Foundation) for seven years, replaced Dr. Ulrich Neumann, who had headed the IMSC since 2001. Neumann continues with the Center as Associate Director for Research. Dr. Chris Kyriakakis moved up from a Thrust Leader to become the IMSC's new Deputy Director.

■ *Incoming EEC Division Director Allen Soyster receives an award at the ICEE-2006 conference.*

**Major Conferences Hosted**

■ International Conference on Reconfigurable Manufacturing is a Success

In May 2005, the ERC for Reconfigurable Manufacturing Systems (RMS) hosted the "CIRP-Sponsored 3rd International Conference on Reconfigurable Manufacturing" at the University of Michigan. (CIRP is the French College International pour la Recherche en Productique.) The conference was extremely well received. The large number of attendees (well over 100) in the last session of the last day of the conference (a panel on "Innovations in Manufacturing—Needs vs.

Reality") is one impressive indicator of its success—a showing that is almost unheard-of in other similar conferences. There were 187 attendees from 17 countries—truly an international conference.

■ UPRM Hosts International Conference on Engineering Education

The International Conference on Engineering Education (ICEE-2006) was held in San Juan, Puerto Rico during July 23-28, 2006. This conference was co-sponsored and co-organized by the University of Puerto Rico, Mayaguez (UPRM), a partner in several ERCs, and the International Network for Engineering Education and Research (iNEER). The purpose of iNEER is to help advance engineering education and research in regions around the world through international linkages and cooperative partnerships. The Chancellor of UPRM, Prof. Jorge Velez Arocho, was the principal host of ICEE-2006; a key planner of the conference was UPRM Prof. Sandra Cruz-Pol, Associate Director of the ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA). A major focus was on the achievements in research and education at UPRM, especially in leveraging partnerships and linkages to achieve program goals. More broadly, presenters described recent innovations and progress achieved around the world in engineering research and education.

■ *NSF Director Dr. Arden Bement gives the keynote address at ICEE-2006.*

# ERC Program Management

Enlightened, consistent program management is one of the keys to the success of this landmark program.

**Program Evolution**

FY 2005 and 2006 were eventful years for the ERC program. In addition to the graduation of five centers, a Program Solicitation was issued for the next cohort of new centers. In response, 136 letters of intent were received, resulting in 109 preliminary proposals, 26 invited full proposals, and nine site visits. At the end of the process, in the early summer of 2006, five of the nine finalists were selected to form the new Class of 2006. These new ERCs are described in the preceding section on "Center Key Events."

The five graduating centers, funded in FY 1994-1995, also are highlighted in the Center Key Events section. From a management perspective, some key points regarding the graduating centers are as follows.

The *Biotechnology Process Engineering Center (BPEC)*, at MIT, was originally established in 1985 as one of the first cohort of six centers that inaugurated the ERC program. BPEC's original focus was on bioprocess engineering for mammalian cell processing. BPEC successfully recompeted in 1994, when the focus of the Center shifted to gene therapy and therapeutic proteins. BPEC I and BPEC II were instrumental in preparing bioreactors and other processing technology needed to support the biotechnology and pharmaceutical industries. The Center's graduates have gone on to become the leaders in these industries. BPEC spearheaded a major educational reform at MIT that led to a new undergraduate major in biological engineering—the first in the nation—and a new requirement for all MIT undergraduates to study biology.

The *Center for Neuromorphic Systems Engineering (CNSE)* was established in 1994 to provide a platform where neurobiologists, mathematicians, and electrical engineers could join together to endow machines with the capability to sense, interact with, learn from, and adapt to their environment with the same ease as living creatures do. CNSE made major contributions to the advancement of neuromorphic control systems through the integration of neurological and engineering perspectives for applications in analog VLSI, optics, olfaction, computational attention/awareness, neuronal control, machine vision, and cognitive neuroprosthetics. The ERC was highly productive in spinning out start-up firms with major market impact. To give just two examples, DigitalPersona was founded by two CNSE undergraduates to commercialize fingerprint identification technology; their approach to password management was adopted by Microsoft for all its fingerprint readers. And Foveon, another CNSE startup, applied a new image sensor technology to produce the world's most sophisticated digital camera. A significant CNSE contribution is the development of a new cadre of faculty, steeped in engineering and neuroscience, now working at the interface of the two fields to develop new insights into control systems that function intelligently in a human-like way. CNSE helped establish the new field of neuromorphic engineering and provided a broad base of faculty from around the world with an opportunity for hands-on training in the field through the Telluride Neuromorphic Workshop. CNSE is now integrated into Caltech's Information Science and Technology (IST) initiative as one of six core centers in the IST, where it continues its work in neuromorphic engineering.

The *Particle Engineering Research Center (PERC)* was established at the University of Florida in 1994 to bring a scientific underpinning to particle processing. The PERC brought particle process systems to the forefront in academic engineering and contributed advancements in particle science and technology across a wide range of areas, including manufacturing, measurement, and nanofunctionalized coatings. The center's international symposia were a key to the growth of this field. Their education program is a model for the second generation of ERCs in its scope and successful impact on course generation and outreach at the precollege level. Because of the close and effective collaboration between industry and the PERC's faculty and students, their industry

| | | |
|---|---|---|
| ERC Program (including support for EERCs) | 59.5% |
| University | 16.9% |
| Industry | 10.8% |
| Other Federal | 6.1% |
| State | 5.0% |
| Other NSF | 1.4% |
| Other Sources | 0.4% |

**Total Direct Support to ERCs FY 2006**

Total support from all sources: $151.2 million.

partners became champions for PERC, marketing Center membership to other firms in the industry. Spin-off firms from PERC contributed new slow-release particles for oral, inhaled, and nasal drug delivery for pain and diseases such as asthma and tuberculosis. In its later years of NSF support, PERC developed collaborations with the UF Medical School that led to an initiative to study nanotoxicology—funded by the EPA, NIH, NSF, and other agencies—that is one of the pillars for the center's self-sufficiency upon graduation.

The *Packaging Research Center (PRC)* was established at Georgia Tech in 1994 to focus on next-generation electronic packaging systems. The System-On-a-Package, or SOP, concept that the PRC pioneered has become an industry standard enabling more efficient processing of multi-purpose, small-scale technology that integrates voice and video. Some 500 PRC graduates have now moved into industry with the knowledge and skills needed to design and manufacture small-scale, complex microelectronic packaging. The PRC also produced an undergraduate text in packaging that has provided the needed foundation to expose undergraduates to this challenging and rewarding interdisciplinary field.

*The Center for Environmentally Benign Semiconductor Manufacturing (CEBSM)* was established at the University of Arizona in 1995 under a competition jointly managed by the ERC Program and the Semiconductor Research Corporation (SRC). The ERC Program and the SRC jointly supported and reviewed the CEBSM for ten years, and now the SRC and Sematech provide the funds to sustain the Center. This ERC produced a wide range of new processing technologies that have reduced the demand for water in semiconductor fabrication and ameliorated its polluting impact on the environment, saving each plant between $250,000 and $2 million per year.

### ERC Budget and Leveraged Support

The ERC Program budget at NSF in FY 2005 was $56.3M; it increased to $57.5M in FY 2006. The table on page 79 shows how those funds were allocated in FY 2005 and FY 2006, with the preponderance supporting the ERCs' base budgets and growth. The remaining funds were used for special-purpose supplements and program review and evaluation costs.

Total direct support for the 22 ERCs from all sources in FY 2005 was slightly over $120M, increasing to $151.2M in FY 2006. The chart at top of this page shows the breakdown of this support in FY 2006 by source. In addition to direct support (funds that are provided to the ERC and flow from its budget for expenditures), ERC faculty also directly receive support for associated projects that are under the scope of the ERC's strategic plan. In FY 2006, total support for associated projects was $46M, with an additional $2.7M in in-kind support, for a grand total of $199.9M.

**Functional Budget Allocations of Support to ERCs FY 2006**


The chart at the top of this page shows the allocation of the ERC's support for different functions. Note that the majority (62%) of the funding was allocated to research.

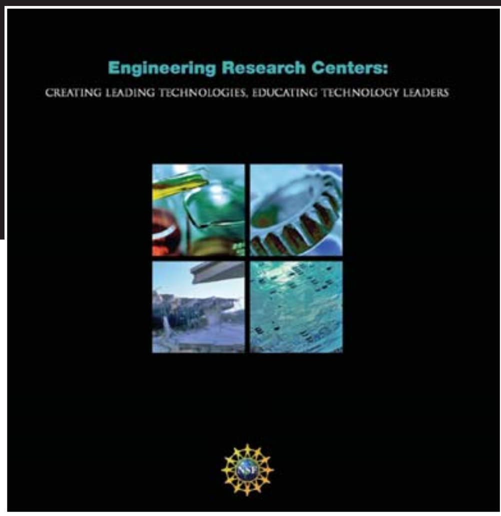
### ERC Program Strategic Planning

In FY 2004, the Committee of Visitors (COV) for the Division of Engineering Education and Centers (EEC) recommended that a study be undertaken to examine the assumptions underlying the ERC program to (a) determine if they are still valid in the 21st century, (b) identify trends for the future, and (c) design the optimal configuration of an ERC of the future. In response, during FY 2005 and 2006, ERC Program Leader Lynn Preston and Dr. Gary Gabriele, the then-Director of the EEC Division, carried out an analysis that examined the currency of the basic ERC key features and determined which ones needed to be eliminated, modified, or added to produce engineering graduates who would be leaders in innovation in an increasingly global economy, in which high-quality research and production facilities are broadly distributed around the world. The methodology for this analysis was as follows:

- Gain input from ERC PDs, the ERCs, and their industrial partners.
- Consult a series of publications by the National Academy of Engineering and the Council on Competitiveness.
- Assess findings from ERC studies/evaluations.
- Gain input from the leaders of the Directorate for Engineering (ENG) through the Engineering Leadership Team (ELT), the Assistant Director for Engineering, his Deputy, and the other ENG division directors.
- Present a preliminary construct to the ENG Advisory Board to gain their advice.

**ERC Program Funding by Category 2005 and 2006**

| | 2005 ($M) | % of Total | 2006 ($M) | % of Total |
|---|---|---|---|---|
| ERC Base Funding | 49.20 | 87.43 | 52.08 | 90.57 |
| ERC Growth | 2.25 | 4.00 | 1.63 | 2.83 |
| REUs | 1.10 | 1.95 | 1.05 | 1.83 |
| RETs | 0.26 | 0.46 | 0.07 | 0.12 |
| Misc. Supplements | 0.75 | 1.33 | 0.02 | 0.03 |
| Connectivity | 0.20 | 0.36 | 0.4 | 0.70 |
| Diversity | 0.20 | 0.36 | 0 | 0.00 |
| Education | 0.55 | 0.98 | 0.84 | 1.46 |
| Review Costs | 0.49 | 0.87 | 0.32 | 0.56 |
| Evaluation & Data Base | 1.27 | 2.26 | 0.4 | 0.70 |
| Translational Research | 0.00 | 0.00 | 0.69 | 1.20 |
| **Total ERC Budget** | **56.27** | | **57.5** | |




*A 2005 brochure on the ERC Program provided examples of notable achievements in research, education and outreach, and technology transfer for each current ERC.*

- Following a motivational talk by Thomas Friedman, author of *The World is Flat!*, at the November 2005 ERC Annual Meeting, engage in a focused dialogue on the candidate key features for new ERCs.
- Recommend new features to the ELT for approval.

The findings indicated that none of the current features should be eliminated, although some should be modified. Industry still needs graduates who have strong disciplinary training and experience in integrating knowledge across disciplines to advance enabling and engineered systems technology. ERCs need active partnerships with industry where industry pays part of the costs of the center. However, it was determined that to remain competitive in a global economy, our graduates had to have more experience in innovation while at the university and a broader exposure to foreign investigators and innovators; the education program should be restructured to be strategically designed to produce graduates who are leaders in innovation; and precollege education should be focused on establishing a long-term partnership between an ERC and a few precollege middle and high schools. In summary, the key features of what we are terming the "Generation 3" (Gen3) ERCs are that they:

- Build a culture of discovery and innovation in academe;
- Link scientific discovery to technological innovation by directly engaging small, innovative firms in the ERC's research teams, using core funds to carry out translational research to speed innovation;
- Build partnerships with at least one academic, state/local government, or other program designed to stimulate entrepreneurship, and with start-up firms, and otherwise speed the translation of academic knowledge into technological innovation;
- Engage ERC students in all phases of the innovation process so they understand what is required to translate fundamental knowledge discoveries into innovations;
- Strategically design education programs to produce creative, innovative engineers;
- Provide faculty and students with cross-cultural, global research experiences through partnerships with foreign universities or other means;
- Build long-term sustained partnerships with a few precollege institutions to increase the enrollment of domestic students in engineering and science degree programs.

**Distribution of Funding Support**
(8 reporting graduated ERCs)

| Annual Funding ($) Cash and in-kind | University Support % | Industry Support % | State Govt. Support % | Other Funding Support % |
|---|---|---|---|---|
| 1. 0.5 M | 0 | 40 | 0 | 60 |
| 2. 1.5 M | 0 | 100 | 0 | 0 |
| 3. 2.02 M | 2 | 3 | 92 | 3 |
| 4. 4.28 M | 13 | 21 | 2 | 64 |
| 5. 4.50 M | 5 | 33 | 5 | 55 |
| 6. 10.8 M | 7 | 23 | 26 | 44 |
| 7. 14.6 M | 6 | 6 | 21 | 67 |
| 8. 26.9 M | 15 | 14 | 0 | 71 |

## Graduated Centers Survey

During FY 2005, ERC Program Director Dr. Vilas Mujumdar conducted a survey of graduated ERCs (those that have completed their term of 10-11 years of ERC Program support). The survey instrument was a 23-item questionnaire inquiring in some detail into the history of the center since graduation, with a particular emphasis on how the center has evolved and how much of its "ERC-ness" it has been able to retain. Ten of the 16 graduated centers surveyed (from the classes of 1985 through 1990) responded.

Eight of the responding centers provided financial data, summarized in the table above. As the table suggests, sources of funding for these centers vary widely, but with one source tending to predominate. In fact, most of the centers reported that they have migrated some of their research toward more industry-driven, applied research since becoming self-sufficient. However, all are still engaged in fundamental research through NSF and other research agency support. In general, their research programs have become more diverse and broader than when they were ERCs. Only two centers reported that their research vision did not change after graduation. All but one of the responding centers reported that they have, however, maintained their systems perspective. About half have developed new academic courses based on the former ERC's vision.

## ERC Program Brochure

During FY 2005 a brochure was produced commemorating 20 years of achievement by the ERC program (see page 80). This was a glossy "coffee-table-style" publication aimed at a variety of nonspecialist audiences, and intended to impart a broad understanding of the goals and achievements of the ERC program and each of the ERCs. Examples of notable achievements in research, education and outreach, and technology transfer were given, along with attractive supporting graphics, for each current ERC.

## Updates on Best Practices

The ERC Best Practices Manual (located on the web at http://www.erc-assoc.org/manual/bp_index.htm) consists of nine chapters covering all aspects of organizing and operating an ERC. These chapters are written by ERC faculty and staff. The various chapters are periodically revised to reflect the evolution of practices and new features of the program.

A new Best Practices chapter on Multi-university ERCs was completed in 2006. During FY 2005 and 2006, revision of three chapters—Center Leadership and Strategic Direction, Research Management, and Administrative Management—was underway. The Administrative Management Chapter was completed in FY 2006. The other two, which depend on input from ERC faculty, are expected to be completed in 2007.

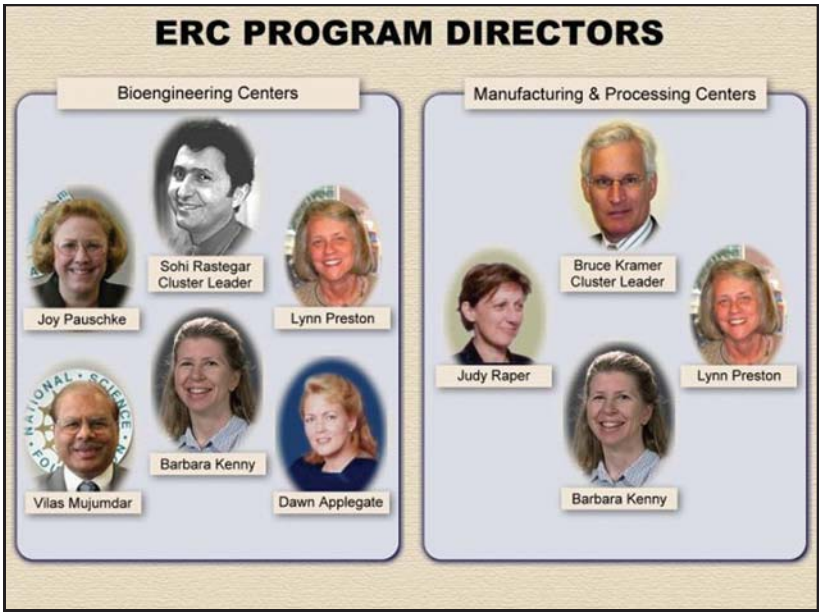
**Diversity in ERCs**

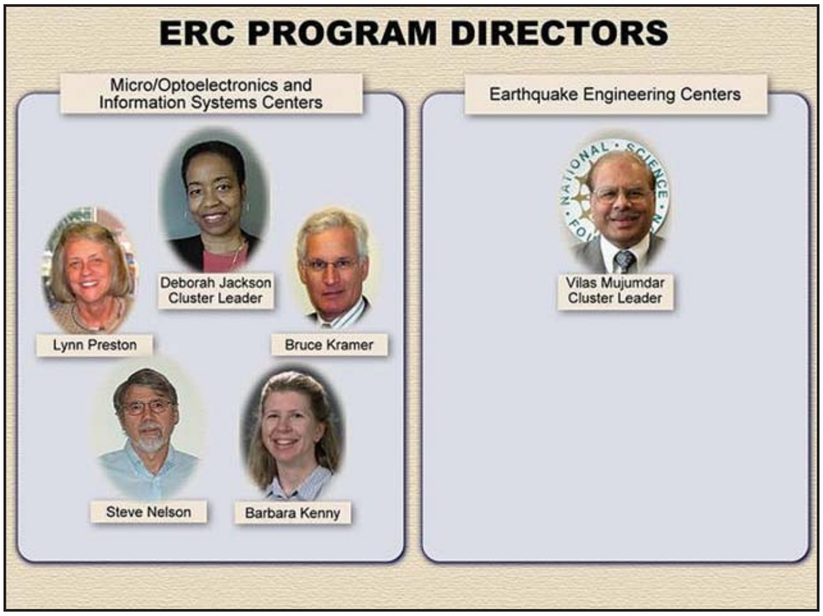
In January 2005, the ERC program developed a formalized diversity policy at the request of the Deputy Director of NSF, Dr. Joseph Bordogna. While overall, ERCs have been quite diverse in terms of the involvement of women and underrepresented minorities, some ERCs were distinctly more diverse than others—although across the board the ERCs are performing better in this regard than engineering colleges as a whole. The policy was introduced into the ERC cooperative agreements after consultation with the ERCs, the NSF General Counsel, and the staff of the Directorate for Education and Human Resources (EHR). EHR provides funding to alliances designed to mentor underrepresented minority undergraduates to go on to graduate school (the Louis B. Stokes Alliances for Minority Participation, or LSAMP) and mentor those in graduate school to become professors (the Alliances for Graduate Education and the Professoriate, or AGEP). The strategy underlying the policy was to form a strategic diversity alliance between an ERC, the departments providing its faculty and students, and its dean of engineering. In addition, since underrepresented minority students are broadly distributed throughout the universities and colleges in the US, a decision was made to require ERCs to develop partnerships with the LSAMPs and AGEPS to reach a broader group of minority students than is possible through partnerships with the Historically Black Colleges and Universities alone.

The detailed diversity policy is presented in the “Improving Diversity in Engineering” section, along with statistics on the participation of women and underrepresented minorities in the ERCs. The expectation is that the new policy will bring continuing increases in the involvement of these traditionally underutilized populations in the cutting-edge work of the ERCs.

## The ERC Team

The NSF ERC Program team consists of the Program management, with Dr. Allen Soyster as Director of the EEC Division and Lynn Preston as Leader of the ERC Program; Program professionals and support staff with responsibilities ranging from education programs to program evaluation and reporting, to communications including websites and publications; and ERC Program Directors in four broad technology areas or "clusters." The members of the 2006 ERC Program Team are pictured to the right.

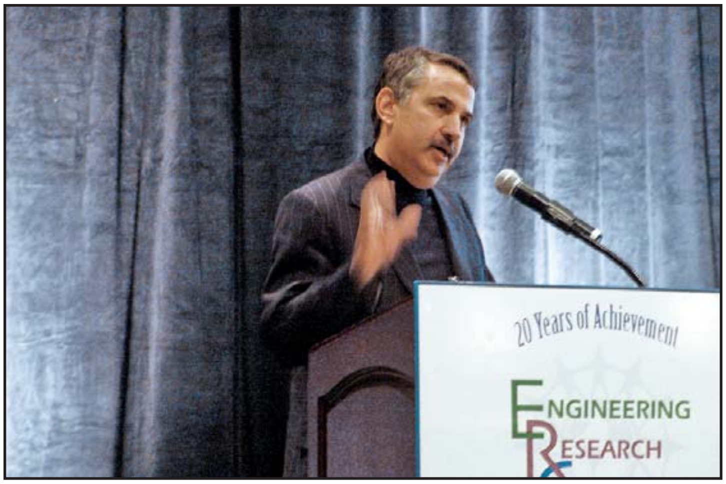
# ERC Program Annual Meeting

The ERC program's Annual Meeting has evolved into a combination of professional conference, town meeting, and family reunion — "like no other government meeting I've ever attended," as one participant recently put it.

Every year a meeting of ERC directors and other key staff, faculty, and students as well as NSF ERC program staff is held in mid-late November in the Washington, DC, area. Non-ERC observers and participants attend the full meeting by invitation only. This meeting is as much a "family reunion" as it is a business and professional meeting—one in which the staff, faculty, and students of the ERCs renew ties with their colleagues at other centers and share experiences and insights relevant to their work. The first day is given to all-day or half-day private retreats of the various ERC leadership teams—Center Directors and Deputy Directors, Education/Outreach Directors, Industrial Liaison Officers, Administrative Managers, Research Thrust Leaders, and Student Leadership Council representatives. In these "closed" meetings, staff and students discuss issues of their own choosing in a direct and candid way aimed at surfacing best practices and problem solutions useful to all.

The remaining two days of the meeting are a blend of plenary sessions organized around timely themes of interest to ERC participants with a large number of breakout sessions carefully designed to address in some details topics relating to the main themes of the meeting. Each breakout is organized by one or more ERC staff members serving as moderator(s) and features speakers or panels around that topic. The emphasis is on devoting considerable time to interactive audience discussion. The breakouts are always lively, interesting, and useful. The meeting also provides a forum for interaction between NSF and the ERCs regarding programs, policies, progress, and plans for the ERC program as a whole. Frequent half-hour breaks facilitate informal one-on-one interactions, augmenting the group discussions in the breakouts.

The 2005 meeting was held November 16-18 at the Hyatt Regency Hotel in Bethesda, MD. In observance of the 20th anniversary of the ERC Program, a film was shown that had originally been produced in 1990 to showcase the program. A filmed epilogue by Dr. Kristina Johnson, then a thrust leader at the University of Colorado's Optoelectronic Systems Center and now Dean of Engineering at Duke University, put in context the aims and achievements of the program in the intervening years. Two early ERC graduates who were featured in the 1990 film returned to describe how their ERC experience had shaped their professional careers.


*(Top) ERC Program Leader Lynn Preston kicks off the 2005 ERC Annual Meeting. (Bottom) Author Thomas Friedman gives the keynote talk on the "Flat World."*

A highlight of the meeting was the keynote talk by Thomas Friedman, author of the best-selling book, *The World Is Flat!*, an analysis of current global economic trends. Friedman's stimulating talk set the stage for the meeting's focus on technology development and engineering education in the global context. NSF Director Arden Bement and luncheon speaker Dr. James Duderstadt, chairman of the recent National Academy of Engineering report, *Engineering Research and America's Future: Meeting the Challenges of a Global Economy,* both elaborated on these themes from different perspectives.

The agenda for this meeting is available at: http://www.erc-assoc.org/annmtg/2005_meeting_files/, along with many of the presentations given at the meeting.

The 2006 ERC Annual Meeting was again held at the Hyatt Regency Bethesda. It continued to address the globalization theme with a focus on the implications of globalization on engineering education and industrial collaboration in particular. Building engineering leadership, innovativeness, and entrepreneurship were topics underlying most of the sessions. Plenary talks by Vivek Paul, a top Indian CEO and venture capitalist who was one of the inspirations for Thomas Friedman's notion of the Flat World; by William Haseltine, a biotechnology industry pioneer who is now starting a pharmaceutical company with operations distributed across several continents; and by Ted Rappaport, an ERC graduate who has built two wireless companies and a large university research group, were highlights of the meeting.

The agenda and presentations at the 2006 meeting are available at: http://www.erc-assoc.org/annmtg/2006_meeting_files/. Video of the three main plenary presentations can be viewed there.

# Honors and Awards

ERCs attract the best and brightest faculty, staff, and students — they are leaders and are recognized as such.

During FY 2005 and 2006, a number of current and former members of the ERC family received significant professional honors and recognition.


**Lynn Preston**, NSF's ERC Program Leader, was named a Fellow of the American Institute for Medical and Biological Engineering (AIMBE) and inducted in February 2006. Ms. Preston was cited for her "…leadership in the National Science Foundation that has helped to establish bioengineering as a major field in academe and industry," through the creation and nurturing of programs in biochemical engineering and biomedical engineering at the Foundation, and through her support of ERCs devoted to various aspects of bioengineering.


**Linda Griffith**, Director of the Biotechnology Process Engineering Center (BPEC) at MIT, was named a MacArthur Fellow in September 2006. One of 25 Fellows to win this "Genius Award" in 2006, Dr. Griffith was cited as "a biotechnologist who is shaping the frontiers of tissue engineering and synthetic regenerative technologies… At the intersection of materials science, cell surface chemistry, physiology, and anatomy," the citation continued, "Griffith is extending the limits of biomedical engineering and its applications for diagnosing disease and regenerating damaged organs." This could be the prototypical definition of an ERC researcher.


In FY 2005, **Claire Gmachl**, now Director of the soon-to-be awarded ERC on Mid-InfraRed Technologies for Health and the Environment (MIRTHE), at Princeton University, was named a MacArthur Fellow. She was cited as "an experimental scientist working at the intersection of technology and fundamental physics in the fields of optics and semiconductor laser technology. A wizard at imagining and creating new designs for solid-state lasers, Gmachl's pioneering work has led to critical advances in the development of Quantum Cascade (QC) lasers."


Farhang Shadman, Director of the University of Arizona's Center for Environmentally Benign Semiconductor Manufacturing (CEBSM), was named Regents' Professor by the Arizona Board of Regents in June 2005. The designation of Regents' Professor is reserved for faculty members at Arizona's public universities "who have demonstrated exceptional scholarship and outstanding achievements." The title "Regents' Professor" serves as recognition of the highest academic merit and is awarded to only three percent of the tenured faculty on each campus.

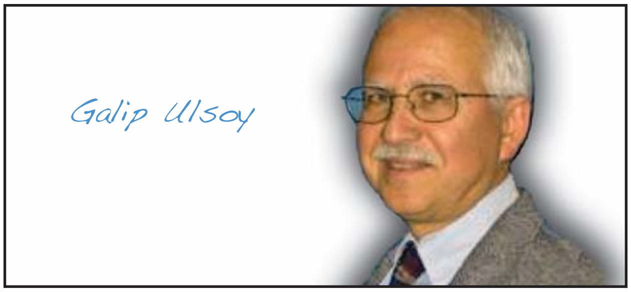
Mark Humayun, Director of the ERC for Biomimetic MicroElectronic Systems at the University of Southern


California, was named by *R&D Magazine* as its 2005 Innovator of the Year. The magazine presented the award to Humayun "for his work on retinal implants and in recognition for his lifelong quest to help the blind to see." Humayun has been working for almost 20 years to develop an artificial retina. Clinical trials have confirmed that the prototype device he and his research group have developed allows previously blind individuals to perceive light and patterns. A more powerful second-generation device will undergo clinical trials starting in 2007.

In June 2005, Max Nikias, founding Director of the Integrated Media Systems Center at the University of

Southern California, was named provost and senior vice president for academic affairs at USC. Dr. Nikias has been part of the USC faculty since 1991 as professor of electrical engineering, and served as dean of the USC Viterbi School of Engineering from 2001-2005 after several years at the helm of the IMSC.


Former Director **Bill Costerton** of the graduated Center for Biofilm Engineering, an ERC at Montana State University, was inducted in November 2005 into the Royal Society of Canada. One of only 63 inductees, Costerton's election was even more unusual in that Canadians living outside Canada are rarely chosen. Costerton is currently the Director of the Center for Biofilms at the University of Southern California.




**Galip Ulsoy**, recently reappointed as Deputy Director of the University of Michigan's Reconfigurable Manufacturing Systems ERC, was elected to the National Academy of Engineering for "research on the dynamics and control of axially moving elastic materials and their implementation in automotive and manufacturing systems."


**Ilesanmi Adesida**, formerly the Associate Director for Education with the graduated Center for Compound Semiconductor Microelectronics at the University of

Illinois at Urbana-Champaign, and now interim Dean of Engineering there, was elected to the National Academy of Engineering for "contributions to the nanometer-scale processing of semiconductor structures and applications in high-performance electronic and optoelectronic devices."


Jun Ni, former Deputy Director of the University of Michigan's Reconfigurable Manufacturing Systems ERC and Professor of Manufacturing, was named the first Dean of the University of Michigan/Shanghai Jiao Tong University (SJTU) joint institute. In addition, Ni will help the UM College of Engineering establish other international partnerships. Most of U-M/SJTU's initial activities will involve collaborative teaching and research by UM Engineering faculty from several departments and the SJTU School of Mechanical Engineering.

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**Engineering Research Centers 2005 – 2006 Program Report**