NSF Engineering Research Centers

CREATING NEW KNOWLEDGE, INNOVATORS AND TECHNOLOGIES FOR OVER 30 YEARS

National Science Foundation

NATIONAL SCIENCE FOUNDATION
ENGINEERING RESEARCH CENTERS

Advanced Combustion Engineering Research Center (ACERC)

Advanced Technology for Large Structural Systems Engineering Research Center (ATLSS)

Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (CENSSIS)

Bioengineering Educational Technologies (VaNTH)

Biomimetic MicroElectronic Systems Engineering Research Center (BMES)

Biotechnology Process Engineering Center (BPEC)

Center for Advanced Engineering Fibers and Films (CAEFF)

Center for Biofilm Engineering (CBE)

Center for Biorenewable Chemicals (CBiRC)

Center for Advanced Electronic Materials Processing (AEMP)

Center for Computer-Integrated Surgical Systems and Technology (CISST)

Center for Emerging Cardiovascular Technologies (ECT-ERC)

Center for Integrated Access Networks (CIAN)

Center for Intelligent Manufacturing Systems (IMS)

Center for Neuromorphic Systems Engineering (CNSE)

Center for Optical Computing Systems (OCS)

Center for Power Electronics Systems (CPES)

Center for Sensorimotor Neural Engineering (CSNE)

Center for Telecommunications Research (CTR)

Center for Wireless Integrated MicroSensing and Systems (WIMS)

Data Storage Systems Center (DSSC)

Engineering Research Center for Bio-mediated and Bio-inspired Geotechnics (CBBG)

Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA)

Engineering Research Center for Compact and Efficient Fluid Power (CCEFP)

Engineering Research Center for Extreme Ultraviolet Science and Technology (EUV)

Engineering Research Center for Mid-InfraRed Technologies for Health and the Environment (MIRTHE)

Engineering Research Center for Net Shape Manufacturing (ERCNSM)

Engineering Research Center for Power Optimization for Electro-Thermal Systems (POETS)

Engineering Research Center for Quantum Energy and Sustainable Solar Technologies (QESST)

Engineering Research Center for Reconfigurable Manufacturing Systems (RMS)

Engineering Research Center for Re-Inventing the Nation's Urban Water Infrastructure (ReNUWIt)

Engineering Research Center for Revolutionizing Metallic Biomaterials (RMB)

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

Engineering Research Center for Ultra-wide Area Resilient Electric Energy Transmission Networks (CURENT)

Future Renewable Electric Energy Delivery and Management Systems Center (FREEDM)

High Performance Computing Collaboratory (HPC2)

Industrial Partnership for Research in Interfacial and Materials Engineering (iPRIME)

Institute for Complex Engineered Systems (ICES)

Institute for Systems Research (ISR)

Integrated Media Systems Center (IMSC)

Mid-America Earthquake Center (MAE)

Micro and Nanotechnology Lab (MNTL)

Multidisciplinary Center for Earthquake Engineering Research (MCEER)

Nanosystems Engineering Research Center Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)

Nanosystems Engineering Research Center for Nanotechnology Enabled Water Treatments Systems (NEWT)

Nanosystems Engineering Research Center for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT)

Nanosystems Engineering Research Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS)

Offshore Technology Research Center (OTRC)

Pacific Earthquake Engineering Research Center (PEER)

Packaging Research Center (PRC)

Particle Engineering Research Center (PERC)

Regenerative Engineering and Medicine Center (REM)

Smart Lighting Engineering Research Center

NSF/SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing (SRC/ERC)

Synthetic Biology Engineering Research Center (Synberc)

University of Washington Engineered Biomaterials Engineering Research Center (UWEB)

ENGINEERING RESEARCH CENTERS: LINKING DISCOVERY TO INNOVATION

Engineering Research Centers (ERCs) are a flagship investment of the National Science Foundation (NSF) to discover and launch the ubiquitous technologies of the future. To date, this investment has led to more than 193 spinoff companies, more than 739 patents, and numerous significant, even revolutionary, research outcomes enabling new technologies.

ERCs create complex, systems-level technologies that address important engineering challenges and help ensure the U.S. remains globally competitive. Their advancements are made possible by integrating the knowledge of many scientific disciplines and collaborating closely with industry. Engineering students of diverse backgrounds benefit from engaging in the ERCs' real-world engineering environments, emerging as a highly trained workforce ready for 21st-century challenges.

Since the program's inception in 1985, NSF has funded 67 ERCs throughout the United States. NSF supports each Center for up to 10 years. During this time the Centers build robust partnerships with industry, universities and other government agencies that will sustain them upon graduation from NSF support.

Currently, NSF supports 19 ERCs. In 2015, NSF established the three newest Centers with a $55.5-million initial investment for breakthrough solutions in compact mobile power, off-grid water treatment and nature-inspired soil engineering.

HISTORY

The ERC program was born out of concern about the state of engineering in the U.S. Industry, academic and government leaders saw that higher education engineering programs often lacked prestige and advanced technical capabilities. What's more, the somewhat narrow, theoretical focus of university research programs was often out of step with industry's applications needs.

In the early 1980s, U.S. manufacturing faced new challenges from global competitors in key areas such as the automotive industry. At the same time, computer industry sectors such as data processing were on the brink of, or already making, revolutionary advances. The role of the engineer would have to change to accommodate these new challenges and opportunities.

NSF sought advice on the purpose and goals of ERCs from engineering leaders through the National Academy of Engineering. The NAE symposium report recommended guidelines for an Engineering Research Center program. This document laid out two primary goals: ERCs should improve engineering research and education, and they should help the U.S. be competitive in global markets. In fact, the goals were nothing less than revolutionizing engineering education and research in the U.S. The main means to accomplish this:

academy-industry partnerships that would, among other things, facilitate knowledge and technology transfer, create interdisciplinary cultures on campus and engage students in advancing technology with industry. "The Engineering Research Center should accustom students to the idea that the engineer does research in order to do, not merely in order to know," wrote Roland W. Schmitt, a General Electric vice president who served as National Science Board chair from 1984 to 1988.

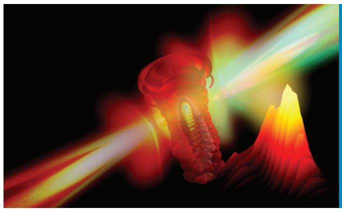
With a budget of $10 million, the inaugural ERC competition attracted 142 proposals from more than 100 institutions. In April 1985, NSF made awards to the first six Centers. George Keyworth, who was then-director of the White House Office of Science and Technology Policy, said the funding round "may have been the toughest grant competition in NSF's history."

The first-generation ERCs focused on manufacturing and commercial design. With the start of the program's second decade, a new generation of Centers began to explore information, microelectronic and biotechnology, and healthcare delivery systems. The third generation of ERCs, started in 2008, is now investigating new opportunities in nanotechnology, sensing and energy systems. At the same time, today's ERCs are nurturing pre-college students' interest in engineering, providing educational opportunities with international partners and fostering a greater role for small business in ERC innovation.

As our world changes in many dimensions—in science, engineering, education, economics, demographics and others—the ERCs will continue to explore emerging engineering research and cultivate the new technologies that will improve the lives of all Americans.

THE ENGINEERING RESEARCH SPECTRUM

Engineering enables every aspect of daily life, from smartphones to drinking water. Researchers, entrepreneurs and educators at Engineering Research Centers supported by the NSF Directorate for Engineering explore and innovate to better people's lives.

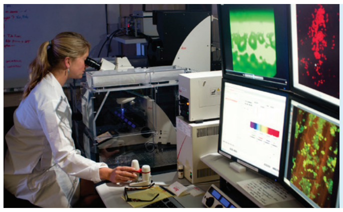


Investments in **advanced manufacturing** materials, processes and systems enable faster, more agile production that is more efficient, precise and sustainable for U.S. industry and consumers, providing greater security and quality of life.

Investigations into **energy and environment** give people options for low-cost, sustainable practices and technologies that protect natural resources, while meeting essential human needs and supporting economic progress.

Fundamental engineering research for new drug delivery systems, assistive technologies, advanced health monitoring and diagnostic systems impacts the capacity and economy of health care delivery and expands the quality of life, improving **human health.**

Funding for **infrastructure** research increases the safety, resilience and "smart" capabilities of the nation's buildings and transportation systems, water and power supplies, as well as information technology and cyber communications networks.



Broadening pathways to science, technology, engineering and math degrees, creating inclusive environments, providing hands-on research opportunities and implementing advances in engineering education help create a highly competent, diverse, flexible and innovative **engineering workforce**—one that is internationally competitive and can meet the changing needs of the American economy.

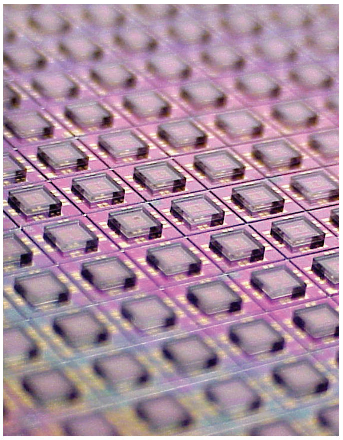
"A center's graduating students are the most important deliverable of the ERC. They leave a lasting legacy through their careers in industry or academia."

– Kim Stelson, director, CCEFP

ENGINEERING RESEARCH CENTERS: OUTCOMES

IMPROVING ELECTRONIC DEVICE CLOCK TECHNOLOGY

In the early 2000s, a graduate student at the **ERC for Wireless Integrated Microsystems** developed an all-silicon alternative to quartz-based timing systems inside electronic devices. The startup Michael McCorquodale founded in 2004, Mobius Microsystems, would go on to be a leader in all-silicon clock generation technology used in cellphones, USB ports and other devices. Mobius' technology enabled lower power consumption and lower total product cost through several advances, including greater levels of circuit integration, better performance and faster time-to-market.



WIDELY USED BIOMETRIC IDENTIFICATION TECHNOLOGY

Fingerprint readers are now part of many people's daily lives, but this technology is only two decades old. Vance Bjorn and Serge Belongie developed the "U. are U." fingerprint identification technology while they were undergraduates at the **Center for Neuromorphic Systems Engineering** at the California Institute of Technology in 1996. The two men established the startup company DigitalPersona and went on to create the world's first mass-market fingerprint recognition device. DigitalPersona became a leader in biometric password management for PCs and corporate information systems. Today, millions of people have used the technology, which is incorporated into certain Microsoft keyboards and other products.

ADVANCING MINIMALLY INVASIVE SURGERY

At the **ERC for Computer-Integrated Surgical Systems and Technology**, based at Johns Hopkins University in Baltimore, Maryland, researchers developed the well-known robot da Vinci that is revolutionizing surgery. The da Vinci surgical system allows surgeons to perform delicate, precise procedures while seated at a console apart from the patient. By manipulating a pair of articulated hand controls, a doctor can remotely guide the movements of da Vinci's instruments through small incisions in the patient. Procedures that require exacting precision and dexterity benefit from the enhanced control enabled by da Vinci and similar tools.

The da Vinci system has been used in minimally invasive surgery on more than 2.5 million patients worldwide.

A NEW WAY TO BOLSTER URBAN WATER SYSTEMS

Using natural systems such as wetlands to improve water quality and create natural habitats can make urban water infrastructures more resilient. The **ERC for Reinventing the Nation's Urban Water Infrastructure (ReNUWIt)** in

> "Our FREEDM energy Internet system is transforming the power industry much the way the Internet transformed the computer industry."
>
> – Iqbal Husain, director, FREEDM

California developed a technology that uses sunlight, algae and bacteria to remove from the water, trace organic chemicals, waterborne pathogens and nutrients.

In design and operation, treatment wetlands rarely manage organic chemical contaminants and provide only modest pathogen removal levels. Improved designs such as ReNUWIt's "open water unit process" cells give wetlands a bigger role in multi-barrier water systems, especially in removing chemical contaminants and controlling pathogenic organisms. After a pilot phase, ReNUWIt partnered with the Orange County Water District to build a full-scale, 10-acre system in the Prado Wetlands.

RESILIENT BIOABSORBABLE IMPLANTS

Each year, millions of people suffer bone fractures that require surgical implants. Many face painful, costly second operations to remove titanium or stainless steel implants. Such non-absorbable implants in infants who've undergone craniofacial reconstruction, for example, must be removed so the skull can grow unimpeded. Implants that fix small bone fractures (fingers, toes, etc.) can leave stiffness, bulging and weakened bones.

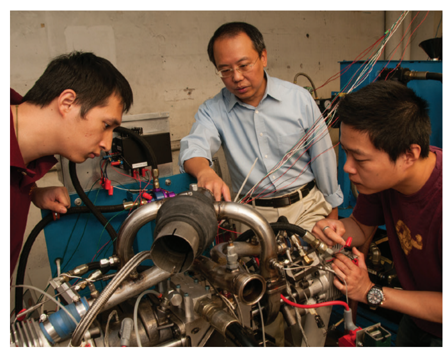
Bioabsorbable polymer implants are available, but aren't always strong enough to rigidly retain the bone geometries surgeons design and set. The **ERC for Revolutionizing Metallic Biomaterials** is working with the startup company Thixomat/nanoMAG on a bioabsorbable alloy, BioMg® 250, which has twice the strength of polymers used in commercial implants and has been shown to stimulate bone growth.

NIMBLE NETWORK TO MONITOR SEVERE WEATHER

Tracking tornados is tricky because they form close to the ground and can shift direction in an instant. However, a network of small radar arrays atop structures such as cell towers and rooftops now allows direct monitoring of the lower atmosphere, providing faster, more precise detection of hazardous weather events. Developed by engineers and designers at the **ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA)**, the short-range X-band arrays enable forecasters to follow a storm cell minute by minute as it grows, and to characterize precipitation type and intensity. The radar's ultra-high-resolution images can help reduce the false alarm rate and improve lead times for communities to take cover. On several occasions, CASA radars enabled storm operation teams to detect last-minute tornado shifts and alert emergency personnel.

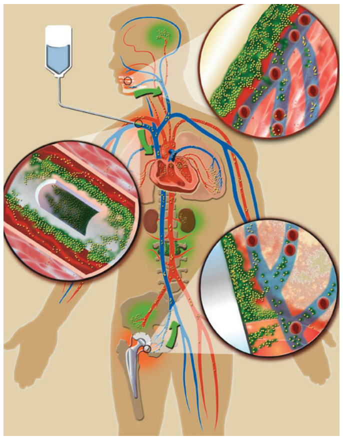
IMPROVING FUEL ECONOMY THROUGH HYDRAULICS

Through development of hydraulic and pneumatic technology, the **ERC for Compact and Efficient Fluid Power (CCEFP)** is transforming fluid power to dramatically reduce energy use and pollution. This network of researchers, educators, students and industry representatives has collaborated on prototype or near-market vehicles that reduce fuel consumption between 25 and 50 percent. Use of the technology, a hybrid hydraulic system that complements gas engines, has improved fuel economy 75 percent in a fleet of refuse trucks in Florida and 50 to 70 percent in package delivery vehicles like those used by UPS and FedEx. An industry-led project aims to bring the technology to passenger cars. Led by Ford, the effort is developing hybrid hydraulic powertrains that deliver 70 mpg and go from 0 to 60 mph in 8 seconds.



PIONEERING BIOFILM ENGINEERING

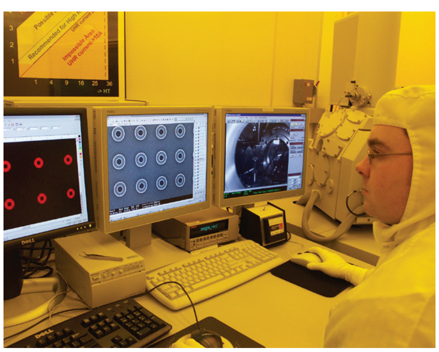
Celebrating 25 years of discovery and advancement in biofilm science and technology, the **Center for Biofilm Engineering (CBE)** is the oldest, largest and best known research center for microbial biofilms. It successfully



integrates pioneering interdisciplinary research, innovative education and effective technology transfer. Center researchers have published over 1,000 peer-reviewed papers on fundamental and applied work ranging from controlling biofilm buildup on medical instruments to developing microbial fuel cells to power portable water quality monitoring devices. Over 730 undergraduates have participated in CBE research and over 235 students have received advanced degrees. Productive interactions with industry through oil and water treatment companies in the early 1990s have expanded to include companies that develop consumer products, specialty chemicals and health care innovations. Continued development of new tools and techniques ensures the center's place at the forefront of biofilm science well into the future.

DRIVING DATA STORAGE INNOVATIONS

The juggernaut of handheld MP3 players, laptops and other devices with high-capacity storage drives grew from the discovery by researchers at the **Data Storage Systems Center (DSSC)** that an underlayer of nickel and

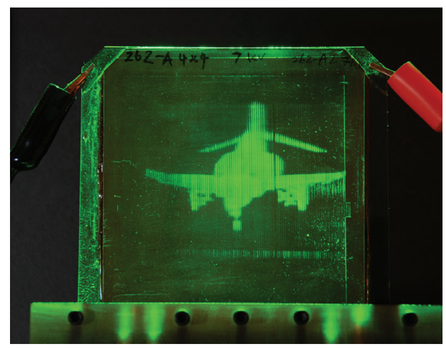


aluminum permits dense packing of data on glass. This is just one of the many groundbreaking data storage innovations developed by DSSC over the last 20 years. Most drives sold since 1995 have contained materials, technology or signal processing algorithms invented at DSSC or whose performance was significantly advanced by DSSC work.

With a focus on hard disk drives, tape systems, optical storage and solid-state storage, DSSC targets nanoscale materials, devices such as optical heads and heads for energy-assisted magnetic recording. The center also innovates through signal processing and systems design. The goal is to increase data storage density and reduce the energy per bit required to store information. Since DSSC began, data storage density has increased approximately 10,000 times. DSSC pursues a portfolio of projects that address industry's most pressing problems as well as projects that go beyond a five-year horizon. Heat-assisted magnetic recording, which was pioneered at DSSC in the early 2000s and adopted by industry as the next recording modality, is poised for commercialization in the next five years.

MAKING A FASTER INTERNET

In 1990, global fixed Internet traffic was 0.001 petabytes per month. In 2010, traffic had increased to 20,197 petabytes per month, a more than 20 million-fold increase. The added traffic threatens to clog the fiberoptic strands that transmit Internet data and once seemed to offer endless capacity. To address these speed and capacity issues, the **ERC for Integrated Access Networks (CIAN)** is developing low-cost, efficient photonics technologies that will enable computers to use light rather than electricity to deliver information. With silicon photonics, researchers can integrate multiple components on silicon chips, the same ones used for microelectronics. Advances by CIAN researchers are beginning to alter the configuration of networks. Because of this, CIAN anticipates that consumers will have access to 5GB wireless networks and high-speed, router-based Internet in the next decade.



In addition to creating a faster Internet, CIAN researchers are turning "Star Wars" science fiction into reality. The movie's holography is now possible in the CIAN labs. The researchers are refining their work to project 3-D holographic video images in near real time. The advance could make full-color, rewritable graphic displays and televisions possible. The video does not require viewers to use special eyewear.

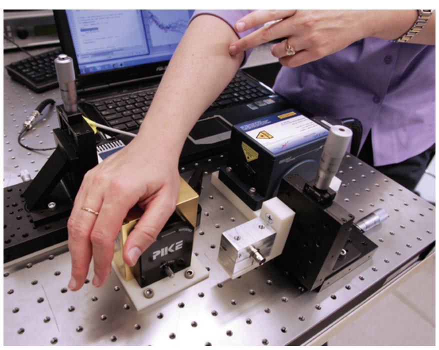
EASY TRAVELS, AMPED-UP SOUND QUALITY

Getting stuck in traffic frays even the steadiest nerves. But ClearPath, a smartphone app developed over more than a decade by engineers at the **Integrated Media Systems Center (IMSC)**, selects the best route for drivers

so that they avoid unnecessary delays and congestion to arrive at their destination on time. A startup company, also named ClearPath, is commercializing the technology, which is protected by three patents. The app uses three years of traffic data to assemble "predicted traffic patterns" and then adjusts the patterns in real time based on delays caused by accidents and weather. The app has a travel time accuracy of 92 percent and yields an 18 percent travel-time savings over routes from Google Maps.

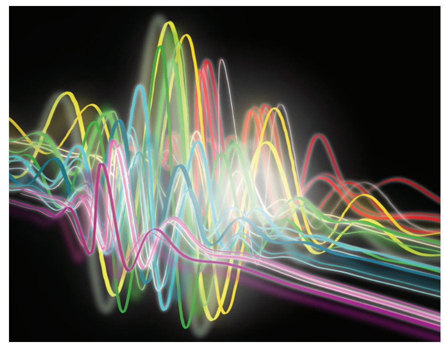
MOVING MID-INFRARED LASERS INTO THE MARKETPLACE

The global market for mid-infrared (IR) lasers is expected to reach over $700 million by 2019, largely due to the adoption of mid-IR lasers in multiple industries from health care to defense. The **Center for Mid-Infrared Technologies for Health and the Environment (MIRTHE)** is at the forefront of this laser surge. By developing new, mid-IR quantum cascade lasers and integrating them into a variety of application-based platforms, MIRTHE researchers are providing novel solutions to dynamic challenges. For diabetic glucose monitoring, one team created a device that relies on laser light to measure blood-sugar levels through the skin on the palm of a hand. Commercialization of the device would provide an alternative to painful finger-pricks for glucose monitoring.



TOOLS FOR NEXT-GENERATION COMPUTER CHIPS AND NANOSCALE IMAGING

Extreme ultraviolet lasers are an integral component in the fabrication of next-generation computer chips. The **Center for Extreme Ultraviolet Science and Technology (ERC EUV)** successfully designed and built a compact EUV laser and optical components to test EUV imaging, patterning and metrology for next-generation chip manufacture and other EUV applications. Their work in the realm of extremely short wavelengths includes development of compact EUV light-based microscopes and creation of a tabletop X-ray source.



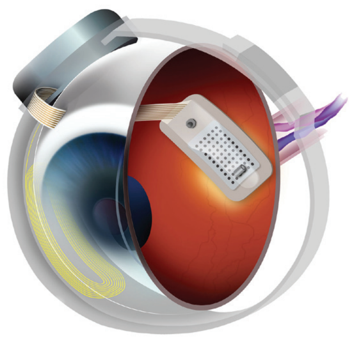
One microscope combines EUV laser ablation with mass spectrometry to provide a 3-D map of the chemical composition of single cells and microorganisms at the nanoscale level. Once perfected, the tabletop X-ray source could provide an opportunity for researchers in multiple fields to perform X-ray studies. Currently, researchers rely on synchrotrons for these experiments. To produce its wide range of wavelengths, from EUV to soft X-rays, a mid-IR laser presses as many as 5,000 longer-wavelength photons together in a process known as high harmonic generation.

"We had six companies spin out within three years. It was a cultural shift."

– Brent Shanks, director, CBiRC

ARTIFICIAL RETINA EXPANDS ACCESS

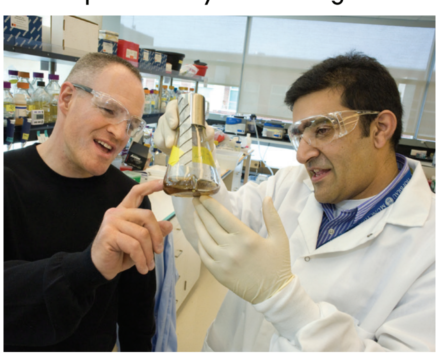
An estimated one in 4,000 people both in the U.S. and abroad have retinitis pigmentosa, an inherited disease that causes sight to gradually decline. To help these and others who experience loss of sight from retinal damage, researchers at the **Center for Biomimetic Microelectronic Systems (BMES)** developed an artificial retina. Spun off through Second Sight, a medical products company, the Argus® II retinal prosthesis became the first medical device to earn U.S. Food and Drug Administration approval as a bionic eye for patients in the U.S. The device helps patients move through their day relying on visual cues rather than touch.



The Argus II is the first artificial retina to receive widespread approval and is offered around the world at approved centers in Canada, Europe, Saudi Arabia, Turkey, the United Kingdom and the U.S.

ENGINEERING MICROBES

Engineering microbes will enable researchers to mix and match parts of synthetic organisms to produce new drugs, alter genomes and develop biofuels. By synthesizing yeast and *E. coli* bacteria, researchers at the **Center for Synthetic Biology (SynBERC)** produced artemisinic acid, a building block of artemisinin, an anti-malarial drug. This more efficient production method resulted in significant cost reductions of this key drug component. Startup company Amyris transferred the technology to Sanofi, which is using it in large-scale production of artemisinin. This production shift ensures that treatment is within reach for the more than 250 million people with malaria.



AUTOMATIC EXTERNAL DEFIBRILLATOR

Heartbeat disorders called arrhythmias (or irregular heartbeat) are responsible for one out of five deaths in the United States. The most common treatment is to use electric shock to restore the heartbeat to its normal rhythm. But devices for treating arrhythmia can be complex and require trained medical personnel to operate. The **Engineering Research Center for Emerging Cardiovascular Technologies** developed devices that proved to be significantly more effective in restoring a normal heartbeat and increasing survival rates in cases of arrhythmia. These shock treatment devices are portable, automatic and simple enough to be used by non-medical personnel. These characteristics make it possible to provide emergency medical assistance for arrhythmias in a variety of settings. The American Heart Association had called for defibrillators to be made available in locations where response by trained medical personnel often is not timely, such as office buildings.

"The ERC program has had a revolutionary impact on universities and industry throughout the nation."

– Lynn Preston, former director, ERC program

ENGINEERING RESEARCH CENTERS: BY THE NUMBERS

67 ERCs funded since 1985

19 ERCs currently supported

$10M Congressional budget appropriation for ERCs in 1985

$64.5M Appropriation for ERCs in 2015

$2.5M Average ERC award per year

28 Number of states

23 Average number of corporate members per center

193 Spinoff companies

1,452 Spinoff companies total employees

2,215 Inventions disclosed

739 Patents awarded

1,339 Licenses issued

42 New full-degree college/university programs based on ERC research

152 New textbooks based on ERC research

4,057 ERC students awarded bachelor's degrees

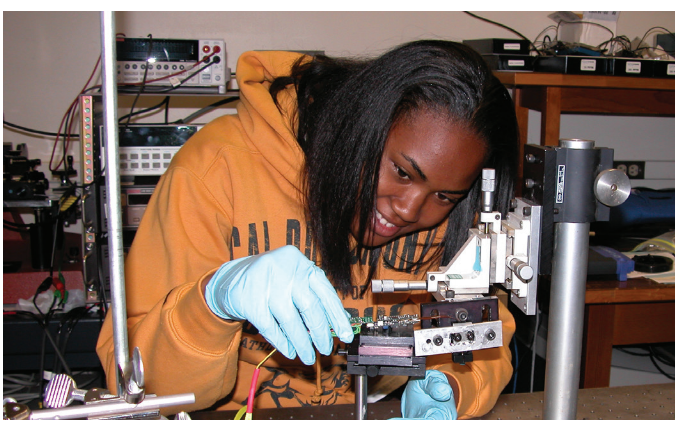
3,918 ERC students awarded master's degrees

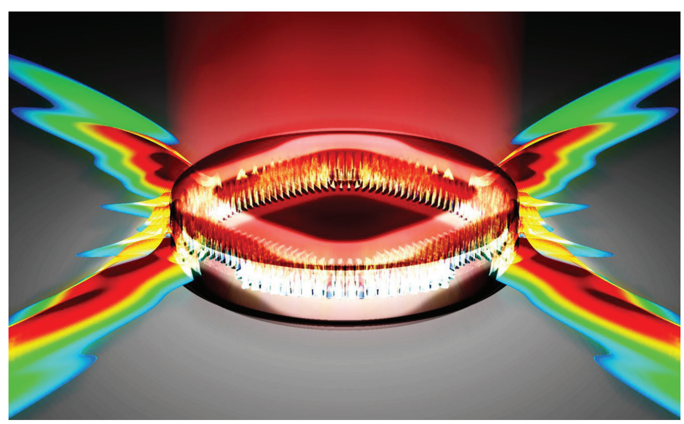
4,432 ERC students awarded doctorates

66% of ERC graduates working in industry

28% of ERC graduates working in academia

6% of ERC graduates working in government





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