Engineering Research Centers: Linking Discovery to Innovation

> *Convergent Research and Innovation through Inclusive Partnerships and Workforce Development*

The Engineering Research Centers (ERC) program was created in 1984 to bring technology-based industry and universities together in an effort to strengthen the competitive position of American industry in the global marketplace. These partnerships established cross-disciplinary centers focused on advancing fundamental engineering knowledge and engineered systems technology while exposing students to the integrative aspects of engineered systems and industrial practice. As a result, over the past 39 years this partnership has produced a wide range of engineered systems and other technologies aimed at spawning whole new industries or radically transforming the product lines, processes, and practices of current industries. At the same time it has produced a new generation of engineering graduates who are highly innovative, diverse, globally engaged, and effective as technology leaders in industry.

NSF has continually refined the goals and purposes of the ERC program to meet the needs of society and of industry in a global economy where the U.S. competitive advantage lies in its capacity to innovate. The goal of today's high-risk, high-payoff ERCs is to create a culture that advances transformational engineered systems technology and education through multidisciplinary, cross-sector partnerships with all stakeholders by means of collaborative, team-based *convergent* research on important and complex societal problems leading to strong societal impact.

To achieve this goal, ERCs have the following four "Foundational Components":
- **Convergent Research (CR)** that has the strong potential to lead to transformative solutions or new fields of study.
- **Engineering Workforce Development (EWD)** that strengthens a robust spectrum of engineering education and pathways occurring at all levels of the Center and all participant stages, and that provides opportunities for engagement by all ERC members including students, faculty, and external partners.
- **Diversity and Culture of Inclusion (DCI)** within an ERC and its various teams that reflects an environment in which all members, including those from groups traditionally underrepresented in engineering, feel valued and welcomed and in which all participants gain mutual benefit.
- An **innovation Ecosystem (IE)** that involves trusted partners who work together to create and enhance the capacity for innovation by finding new ways to deliver value with positive societal impact that will outlast the lifetime of the ERC. This includes implementing effective translational efforts from ideation to implementation, workforce development in support of the enterprise, and deliberate efforts to attract funding and resources.

From their inception the ERCs have embodied NSF's strategic interests in the integration of research and education, the integration of science and engineering disciplines, partnerships between academe and industry, and strengthening the engineering workforce to meet the nation's needs in a global economy. In many ways the program has 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. This history is described in the book, *Agents of Change: NSF's Engineering Research Centers* <https://erc-history.erc-assoc.org/>.

Each ERC is established as a 3-way partnership involving academe, industry, and NSF (in some cases with the participation of state, local, and/or other Federal government agencies). Total annual funding provided directly to each center by the ERC Program starts at $3.5 million and ramps up to a maximum of $6.0 million.

NSF funds each ERC for up to 10 years. Since 1985, a total of 80 ERCs and 3 Earthquake ERCs[*] have been formed across the United States, with 19 ERCs currently in operation. Surveys of industry employers have shown that ERC graduates are viewed by 80% of their supervisors as being more productive than their peers because their ERC experience has taught them how to integrate knowledge across disciplines and manage teams to advance technology. Studies of the impacts of ERC-generated technologies have found that the economic value of products and processes deriving from the ERCs is in the high tens of billions of dollars—an impressive return on NSF's total investment of under $2 billion—with some centers having had a transformational impact on their field of engineering and technology.

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[*] *Three Earthquake Engineering Research Centers were established in 1997 with funds outside of the ERC Program but were funded and managed by the ERC Program from 1999 through their graduation from NSF support.*

The major technological areas upon which current ERCs focus are:

- Advanced Manufacturing
- Biotechnology and Health Care
- Energy, Sustainability, and Infrastructure
- Microelectronics, Sensing, and IT

ADVANCED MANUFACTURING

CMaT: ERC for Cell Manufacturing Technologies (Class of 2017)
Georgia Institute of Technology (lead institution) in partnership with the University of Georgia, the University of Wisconsin-Madison and the University of Puerto Rico-Mayaguez

ERC-HAMMER: ERC for Hybrid Autonomous Manufacturing Moving from Evolution to Revolution (Class of 2022)
The Ohio State University (lead institution) in partnership with Case Western Reserve University, North Carolina Agricultural and Technical State University, Northwestern University and the University of Tennessee, Knoxville

TARDISS: ERC for Transformation of American Rubber through Domestic Innovation for Supply Security (Class of 2024)
The Ohio State University (lead institution) in partnership with Caltech, North Carolina State University, Texas Tech University, and the University of California, Merced

BIOTECHNOLOGY AND HEALTH CARE

CELL-MET: Nanosystems ERC for Cellular Metamaterials (Class of 2017)
Boston University (lead institution) in partnership with the University of Michigan and Florida International University

PreMiEr: ERC for Precision Microbiome Engineering (Class of 2022)
Duke University (lead institution) in partnership with North Carolina Agricultural and Technical State University, North Carolina State University, the University of North Carolina at Chapel Hill and the University of North Carolina at Charlotte

ATP-Bio: ERC for Advanced Technologies for Preservation of Biological Systems (Class of 2020)
University of Minnesota (lead institution) in partnership with Massachusetts General Hospital, the University of California, Berkeley, and the University of California, Riverside

PATHS-UP: ERC for Precise Advanced Technologies and Health Systems for Underserved Populations (Class of 2017) Texas A&M University (lead institution) in partnership with the University of California at Los Angeles, Rice University and Florida International University

ENERGY, SUSTAINABILITY, AND INFRASTRUCTURE

CBBG: ERC for Bio-mediated and Bio-inspired Geotechnics (Class of 2015)
Arizona State University (lead institution) in partnership with the Georgia Institute of Technology, New Mexico State University, and the University of California, Davis

EARTH: ERC for Environmentally Applied Refrigerant Technology Hub (Class of 2024)
University of Kansas (lead institution) in partnership with Lehigh University, the University of Hawaii, the University of Maryland, the University of Notre Dame, and the University of South Dakota

CISTAR: ERC for Innovative and Strategic Transformation of Alkane Resources (Class of 2017)
Purdue University (lead institution) in partnership with the University of New Mexico, Northwestern University, the University of Notre Dame and the University of Texas at Austin

NEWT: Nanosystems ERC for Nanotechnology Enabled Water Treatment Systems (Class of 2015)
Rice University (lead institution) in partnership with Arizona State University, the University of Texas at El Paso and Yale University

CASFER: ERC for Advancing Sustainable and Distributed Fertilizer Production (Class of 2022)
Texas Tech University (lead institution) in partnership with Case Western Reserve University, Florida A&M University, Georgia Tech and MIT

ASPIRE: ERC for Advancing Sustainability through Powered Infrastructure for Roadway Electrification (Class of 2020)
Utah State University (lead institution) in partnership with Purdue University, the University of Colorado, and the University of Texas at El Paso

CURB: ERC for Carbon Utilization Redesign through Biomanufacturing-Empowered Decarbonization (Class of 2024)
Washington University in St. Louis (lead institution) in partnership with the University of Delaware, Prairie View A&M University, and Texas A&M University

MICROELECTRONICS, SENSING, AND IT

CQN: ERC for Quantum Networks (Class of 2020)
University of Arizona (lead institution) in partnership with Harvard University, Massachusetts Institute of Technology, and Yale University

HAND: ERC for Human AugmentatioN via Dexterity (Class of 2024)
Northwestern University (lead institution) in partnership with Carnegie Mellon University, Florida A&M University, and Texas A&M University, and with engagement of MIT

CS3: Center for Smart Streetscapes (Class of 2022)
Columbia University (lead institution) in partnership with Florida Atlantic University, Lehman College, Rutgers University and the University of Central Florida

POETS: ERC for Power Optimization for Electro-Thermal Systems (Class of 2015)
University of Illinois at Urbana-Champaign in partnership with Howard University, Stanford University, and the University of Arkansas

IoT4Ag: ERC for the Internet of Things for Precision Agriculture (Class of 2020)
University of Pennsylvania (lead institution) in partnership with Purdue University, the University of California, Merced, and the University of Florida

At the end of their ten-year life-cycle as NSF-supported Engineering Research Centers, most ERCs graduate from NSF support and become self-sustaining. Currently there are 44 graduated and self-sustaining bpecERCs and Earthquake ERCs:

Manufacturing

CEBSM: ERC for Environmentally Benign Semiconductor Manufacturing — University of Arizona, Tucson, AZ (lead institution) in partnership with Arizona State University, the University of California at Berkeley, Cornell University, MIT, and Stanford University (established in 1996, graduated in 2006) [this ERC was jointly funded by the Semiconductor Research Corporation]

EDRC: ERC for Engineering Design (now the Institute for Complex Engineered Systems) — Carnegie Mellon University, Pittsburgh, PA (established in 1986, graduated in 1997)

CAEFF: Center for Advanced Engineering of Fibers and Films — Clemson University, Clemson, SC (lead institution) in partnership with MIT (established in 1998, graduated in 2008)

PERC: Particle Engineering Research Center — University of Florida, Gainesville, FL (established in 1995, graduated in 2005)

CBiRC: ERC for Biorenewable Chemicals — Iowa State University, Ames, IA (lead institution) in partnership with the University of California, Irvine, the University of New Mexico, Rice University, the University of Virginia, and the University of Wisconsin-Madison (stablished in 2008, graduated in 2018)

SRC: Systems Research Center (now the Institute for Systems Research) — University of Maryland/Harvard University (established in 1985, graduated in 1994)

CIE: Center for Interfacial Engineering (now the Industrial Partnership for Research in Interfacial and Materials Engineering, or iPrime) — University of Minnesota, Minneapolis, MN (established in 1988, graduated in 1999)

CCEFP: ERC in Compact and Efficient Fluid Power — University of Minnesota, Minneapolis, MN (lead institution) in partnership with Georgia Institute of Technology, Purdue University, the University of Illinois at Urbana-Champaign, Milwaukee School of Engineering, North Carolina A&T University, and Vanderbilt University (established in 2006, graduated in 2017)

C-SOPS: Center for Structured Organic Particulate Systems — Rutgers University, New Brunswick, NJ (lead institution) in partnership with Purdue University, New Jersey Institute of Technology, and the University of Puerto Rico at Mayagüez Francisco (established in 2006, graduated in 2017)

NASCENT: Nanosystems ERC for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies — The University of Texas at Austin (lead institution) in partnership with the University of New Mexico and the University of California, Berkeley (established in 2012, graduated in 2022)

Biotechnology and Health Care

GTEC: ERC for the Engineering of Living Tissues (now the Regenerative Engineering and Medicine Research Center) — Georgia Institute of Technology, Atlanta, GA (lead institution) in partnership with Emory University (established in 1998, graduated in 2008)

CISST: Center for Computer-Integrated Surgical Systems and Technology — Johns Hopkins University, Baltimore, MD (lead institution) in partnership with the Brigham and Women's Hospital, Carnegie Mellon University, the Johns Hopkins University Hospital, MIT,

and Shady Side Hospital (established in 1998, graduated in 2008)

CBE: Center for Biofilm Engineering — Montana State University, Bozeman, MO (established in 1990, graduated in 2001)

RMB ERC: ERC for Revolutionizing Metallic Biomaterials — North Carolina A&T State University, Greensboro, NC (lead institution) in partnership with the University of Cincinnati and the University of Pittsburgh (established in 2008, graduated in 2018)

ASSIST: Nanosystems ERC for Advanced Self-Powered Systems of Integrated Sensors and Technologies — North Carolina State University, Raleigh, NC (lead institution) in partnership with Pennsylvania State University, Florida International University, and University of Virginia (established in 2012, graduated in 2022)

BMES: ERC for Biomimetic MicroElectronic Systems — University of Southern California - Keck School of Medicine and Viterbi School of Engineering, Los Angeles, CA (lead institution) in partnership with California Institute of Technology and the University of California, Santa Cruz (established in 2003, graduated in 2013)

VaNTH: ERC for Bioengineering Educational Technologies — Vanderbilt University, Nashville, TN (lead institution) in partnership with Northwestern University, the Harvard University-MIT Division of Health Sciences and Technology, and the University of Texas at Austin (established in 1999, graduated in 2007)

UWEB: Engineered Biomaterials Engineering Research Center — University of Washington, Seattle, WA (established in 1996, graduated in 2007)

CNT: Engineering Research Center for Neurotechnology — University of Washington, Seattle, WA (lead institution) in partnership with the Massachusetts Institute of Technology and San Diego State University (established in 2011, graduated in 2021)

Energy, Environment, and Infrastructure

QESST: ERC for Quantum Energy and Sustainable Solar Technologies (co-funded with DOE) — Arizona State University, Tempe, AZ (lead institution) in partnership with the California Institute of Technology, the University of Delaware, the Georgia Institute of Technology, the University of Houston, the Massachusetts Institute of Technology, and the

University of New Mexico (established in 2011, graduated in 2021)

ACERC: Advanced Combustion Engineering Research Center — Brigham Young University/University of Utah (established in 1986, graduated in 1997)

MCEER: Multidisciplinary Center for Earthquake Engineering Research — University at Buffalo (lead institution) in partnership with Cornell University, University of Delaware, University of Nevada at Reno, and University of Southern California, as well as other collaborating institutions and private entities throughout the U.S. (established in 1997, graduated in 2007)

ATLSS: Center for Advanced Technology for Large Structural Systems — Lehigh University, Bethlehem, PA (established in 1986, graduated in 1997)

PEER: Pacific Earthquake Engineering Research Center — University of California at Berkeley, CA (lead institution) in partnership with California Institute of Technology, Stanford University, University of California at Davis, University of California at Irvine, University of California at Los Angeles, University of California at San Diego, the University of Southern California, the University of Washington, and nine affiliate institutions (established in 1997, graduated in 2007)

MAE Center: Mid-America Earthquake Center — University of Illinois at Urbana-Champaign, IL (lead institution) in partnership with Georgia Institute of Technology, the University of Memphis, MIT, St. Louis University, Texas A&M University, and Washington University (established in 1997, graduated in 2008)

FREEDM: ERC for Future Renewable Electric Energy Delivery and Management Systems — North Carolina State University, Raleigh, NC (lead institution) in partnership with Arizona State University, Florida A&M University, Florida State University, Missouri University of Science and Technology (established in 2008, graduated in 2018)

OTRC: Offshore Technology Research Center — Texas A&M University/University of Texas (established in 1988, graduated in 1999)

Micro/Optoelectronics, Sensing, and IT

CIAN: ERC for Integrated Access Networks — University of Arizona, Tucson, AZ (lead institution) in partnership with the California Institute of Technology, Columbia University, Norfolk State University, Stanford University, Tuskegee University, the Universities of California at Berkeley, San Diego, and Los Angeles, and

the University of Southern California (established in 2008, graduated in 2018)

TANMS: Nanosystems ERC for Translational Applications of Nanoscale Multiferroic Systems — University of California, Los Angeles (lead institution) in partnership with Cornell University, the University of California, Berkeley, California State University, Northridge; Northeastern University, and the University of Texas at Dallas (established in 2012, graduated in 2022)

DSSC: Data Storage Systems Center — Carnegie Mellon University, Pittsburgh, PA (established in 1990, graduated in 2001)

EUV ERC: ERC for Extreme Ultraviolet Science & Technology Colorado State University, Fort Collins, CO (lead institution) in partnership with the University of Colorado at Boulder and the University of California at Berkeley (established in 2003, graduated in 2013)

PRC: Packaging Research Center (now the 3D Systems Packaging Research Center) — Georgia Institute of Technology, Atlanta, GA (established in 1995, graduated in 2005)

CCSM: Center for Compound Semiconductor Microelectronics — University of Illinois at Urbana-Champaign (established in 1986, graduated in 1997)

CASA: ERC for Collaborative Adaptive Sensing of the Atmosphere — University of Massachusetts, Amherst, MA (lead institution) in partnership with Colorado State University, University of Oklahoma, and University of Puerto Rico at Mayagüez (established in 2003, graduated in 2013)

LESA: Lighting Enabled Systems & Applications ERC — Rensselaer Polytechnic Institute, Troy, NY (lead institution) in partnership with Boston University and the University of New Mexico (established in 2008, graduated in 2018)

CCFS: Center for Computational Field Simulation — Mississippi State University, Mississippi State, MS (established in 1990, graduated in 2001)

WIMS: Center for Wireless Integrated MicroSystems — University of Michigan, Ann Arbor, MI (lead institution) in partnership with Michigan State University and Michigan Technological University (established in 2000, graduated in 2010)

CenSSIS: Center for Subsurface Sensing and Imaging Systems — (now the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems) Northeastern University, Boston, MA (lead institution) in partnership with Boston University, Rensselaer Polytechnic Institute, University of Puerto Rico at Mayagüez, Brigham and Women's Hospital, Lawrence Livermore National Laboratory, Massachusetts General Hospital, and Woods Hole Oceanographic Institution (established in 2000, graduated in 2010)

MIRTHE: ERC on Mid-Infrared Technologies for Health and the Environment — Princeton University, Princeton, NJ (lead institution) in partnership with the City University of New York, the Johns Hopkins University, Texas A&M University, the University of Maryland–Baltimore County, and Rice University (established in 2006, graduated in 2016)

IMSC: Integrated Media Systems Center — University of Southern California, Los Angeles, CA (established in 1996, graduated in 2007)

CURENT: ERC for Ultra-wide Area Resilient Electric Energy Transmission Networks (co-funded with DOE) — University of Tennessee–Knoxville (lead institution) in partnership with Northeastern University, Rensselaer Polytechnic Institute, and Tuskegee University (established in 2011, graduated in 2021)

CPES: Center for Power Electronics Systems — Virginia Polytechnic Institute & State University, Blacksburg, VA (lead institution) in partnership with North Carolina A&T State University, University of Puerto Rico at Mayagüez, Rensselaer Polytechnic Institute, and University of Wisconsin at Madison (established in 1998, graduated in 2008)