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INNOVATIONS HIGHLIGHTS FROM 40 YEARS OF NSF ENGINEERING RESEARCH CENTERS:

A Legacy of Leadership in U.S. Engineering Innovation

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INNOVATIONS HIGHLIGHTS FROM 40 YEARS OF NSF ENGINEERING RESEARCH CENTERS:
A Legacy of Leadership in U.S. Engineering Innovation

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INTRODUCTION

The ERC Model: Advancing Society Through Research, Policy, and Partnership

For four decades, the National Science Foundation's Engineering Research Centers (ERC) program in the Division of Engineering Education and Centers within the Directorate for Engineering has stood at the intersection of innovation, strategic investment, and stakeholder collaboration—advancing solutions to some of the most pressing technological and societal challenges of our time. The NSF ERC program has pushed academic engineering research to focus on real-world problems by requiring the funded researchers to interact with industry and economic development organizations to foster commercialization of the technologies they develop and thus have a positive economic and societal impact. It also requires workforce development programs in which engineering education is integrated with research and technology development, as well as outreach programs beyond the participating universities. These efforts have yielded a solid pipeline of science, technology, engineering and mathematics (STEM) students pursuing technical degrees and strengthened the STEM base in the general population.

Launched in 1984, the ERC program was designed as a policy response to revitalize U.S. industrial competitiveness by transforming academic engineering research into a collaborative, use-inspired enterprise. Since then, the program has evolved into one of NSF flagship programs, supporting 83 centers, leveraging more than $2 billion in federal investment, and contributing to an estimated $322 billion in downstream private-sector investment and $237 billion in product and process revenues. Technology that originated from ERCs span sectors from advanced manufacturing and digital health to robotics, telecommunications, and biotechnology, helping shape industries and markets now valued in hundreds of billions of dollars and essential to the global innovation economy.

At the heart of this success lies a commitment to stakeholder engagement. ERCs have created dynamic ecosystems that amplify the reach and relevance of federally funded research by bringing together academia, industry, local and regional governments, economic development agencies, and members of the impacted communities to co-design technologies and workforce strategies. Being aware of their needs and addressing them early in the technology development process mitigates risks and roadblocks to later adoption. This collaborative framework has accelerated technology's path from lab to market, enhancing its relevance, scalability and societal impact. Such an innovative approach maximizes the societal return on investment of taxpayer dollars invested in the program. As the latest NSF ERC solicitation states:

> *The goal of the ERC program has traditionally been to integrate engineering research and education with technological innovation to transform and improve national prosperity, health, and security. Building upon this tradition, NSF is interested in supporting ERCs to develop and advance engineered systems, which if successful, will have a high societal Impact.*

NSF ERCs AT THE FOREFRONT FOR TECHNOLOGICAL ADVANCEMENT
The Path of Innovation

New Industries and New Fields

Some of ERC technologies have been so innovative that they helped spearhead incipient industries. The following examples illustrate how NSF ERC innovations have significantly advanced the development of groundbreaking products and services.

Figure 1: (Credit: National Science Foundation
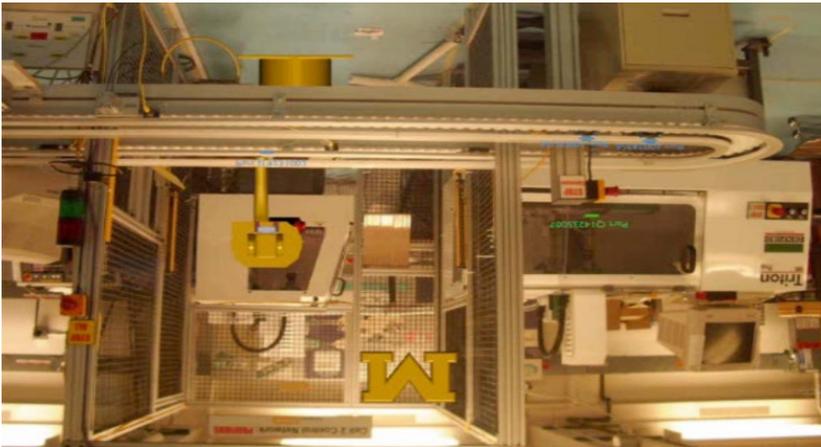
Reconfigurable Manufacturing

Figure 2: One aim of NSF RMS research was "Virtual Fusion," the integration of simulation onto the real-world factory floor (Credit: Harrison, W, Moyne, J., and Tilbury, D.)

The University of Michigan-led NSF ERC for Reconfigurable Manufacturing Systems (NSF RMS) (1996-2007) created the field of reconfigurable manufacturing systems (RMS), where manufacturing systems are designed from the beginning to be able to change their structure and have in-line product-quality evaluation, resulting in a cost-effective method to respond to changes in global market needs. It was initially *implemented in the automotive industry through the ERC's industry partners General Motors and Ford Motor Company, and since then it has been adopted across diverse industries worldwide, from aerospace to pharmaceuticals.* RMS also helped revolutionize the digital automation of manufacturing, dubbed Industry 3.0, and its mindset continues to influence the development of Next Generation Manufacturing Systems (NGMS) and Industry 4.0, as more manufacturers incorporate emerging technologies such as Artificial Intelligence (AI), machine learning, Internet of Things (IoT), and additive manufacturing into their operations.
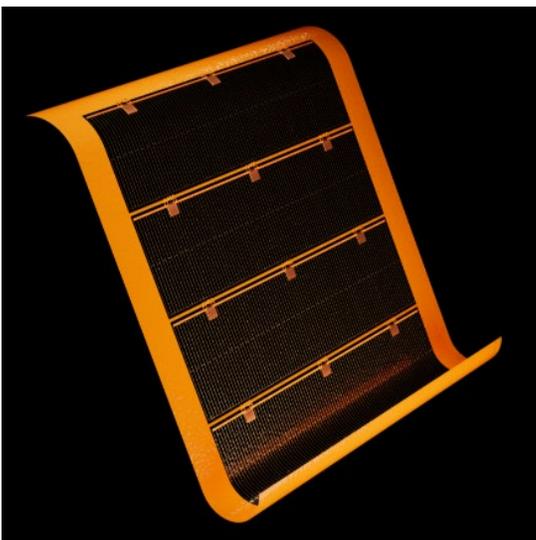
Space Based Photovoltaics

Figure 3: Flexible solar power for space applications (Credit: Solestial)

Satellites and spacecraft in the inner solar system generally use photovoltaic (PV) solar panels to power their operation. In space, PV can generate electricity 24 hours per day. Additionally, the solar radiation is more intense in space, so a lot of power that can be produced. However, this *leads to 8 times faster degradation of the panels as compared with the degradation on Earth.* Another important consideration for PV panels for space applications is their weight. For obvious reasons the launch cost grows with weight.

Increasing radiation resistance, decreasing weight, and lowering cost of PV panels are key enablers for space applications. Solestial (originally Regher Solar), one of the startups from the Arizona State University-led NSF ERC for Quantum Energy and Sustainable Solar Technologies (NSF QESST, 2011-2023), developed silicon solar cells that self-heal radiation damage under sunlight at a normal operating temperature of 80°C. They are packaged in an ultrathin, flexible, low-mass solar blanket that can be produced using automation, resulting in costs 90% lower than incumbent technologies. Lastly, they are designed to achieve minimum degradation for up to 10 years in low Earth orbit, as was independently verified.

Solestial's high-efficiency, low-weight PV panels with long lifetimes can enable more versatility in satellite design. They can support the implementation of some new innovations in the market that require extra power, such as more powerful on-board computers and instruments that can render higher-resolution Earth images.

In addition, for several decades the concept of space-based solar power generation for use on Earth has been talked about, but current PV technology is too expensive per Watt generated to launch because of their weight. With panels such as Solestial's, the costs of launch, repair, and replacement could at last make space-based solar industry economically viable.

ERCs are behind the standards that safeguard our infrastructure and our health.

Synthetic Biology

The UC Berkeley-led Synthetic Biology ERC (Synberc) (2006-2016) played a major role in the evolution of the synthetic biology industry, developing the technologies to build biological components and assemble them into integrated systems like natural ones. It was the first effort to treat biology as an engineering discipline that systematizes modular design and construction using standardized biological parts. *Researchers at the ERC did early work on CRISPR, the "genetic scissors" technology that allow scientists to modify the DNA of living organisms.* CRISPR's potential benefits include faster clinical trials, more resilient crops and livestock, and revolutionary treatments for inherited diseases and cancer, and later researchers were the recipients of the 2020 Nobel Prize in Chemistry.

Standards for Infrastructure and Infection Control

Technical standards are important because they provide a common set of rules and guidelines that can be followed by organizations to ensure safety and reduce the risks of accidents and injuries. A couple of examples of the influence of NSF ERCs on standards-setting are given here.

The Lehigh University-led NSF Advanced Technology for Large Structural Systems Engineering Research Center (NSF ATLSS) (1987-1997) has played a *major role in developing many of the modern transportation and infrastructure design codes, including those of the American Association of State Highway and Transportation Officials (AASHTO), American Institute of Steel Construction (AISC), American Welding Society (AWS), and the American Railway Engineering and Maintenance-of-Way Association (AREMA).*

Biofilms are layers of bacteria and other living microorganisms that stick to surfaces. The Montana University-led NSF Center for Biofilm Engineering (NSF CBE) (1990-2001) launched the field of biofilm engineering and led to the American Society for Testing and Materials International (ASTM) setting worldwide standards for biofilm control. One method, ASTM E2871-21, in concert with *NSF CBE's scientific recommendations, formed the basis of the U.S. Environmental Protection Agency (EPA)'s 2017 standard testing*

methods for evaluating the efficacy of antimicrobial pesticides against biofilm bacteria. These standards and similar one's help ensure that cleaning products are effective and help to slow the spread of antimicrobial resistance in medical settings

Computing and Consumer Products

Hard Disk Drives and Cloud Computing

Hard disk drives (HDDs) are ubiquitous and have been the standard memory medium for the computer industry for decades. They are also the data storage medium of choice for all cloud computing and storage systems, thus enabling, as an example, all the social media platforms that are so widely used. HDDs are envisioned to continue to be the workhorse of cloud activities even with the rapid advances in solid state drives (SSDs), due to their unlimited read/write capabilities and thus longer lifespan.

Figure 4: Hard drive (royalty-free image from Pexels, https://bit.ly/3Cmxu7V)

The Carnegie Mellon University NSF Data Storage Systems Center (NSF DSSC) ERC (1990-2001) was the world's largest academic research center for data storage. This ERC was instrumental in advancing HDD technology towards higher storage density, and thus higher capacity and smaller footprint. Researchers in the center realized the limitations of the prevailing longitudinal magnetic recording (LMR) technology, in use since the 1950s, and demonstrated the advantages of perpendicular magnetic recording (PMR) technology. Seagate commercialized the technology, and in 2005 launched HDDs based on PMR. The technology has been used in all HDDs until recently, when the more advanced heat magnetic recording (HAMR) technology became commercially available, a technology that DSSC also worked on past the period of NSF ERC program funding. In 2017, Seagate announced that HAMR drives were in pre-pilot trials at customers, and in 2023 they shipped the first commercial 32TB drives, thus continuing the impact of this long-graduated ERC on computer users everywhere.

Faster Streaming Services and More Efficient Enterprises Communications

Today, people and businesses access files and applications on the cloud every day. Underlying the ability to provide such services are data centers — physical facilities that house the infrastructure and computing equipment necessary to process the vast amounts of data generated. Data centers are also key for enterprises for their own storage and data processing needs.

Reliability, security, high speed, and cost-efficiency are the key requirements for data centers. For certain applications such as financial trading, streaming services and real-time enterprise data processing, speed is critical for optimal performance. Network components that have a high impact on speed are switches, a type of hardware that allows devices to communicate with each other and share information.

The University of Arizona-based Center for Integrated Access Networks NSF ERC (NSF CIAN) (2008-2019) developed a light-based technology to enable higher-bandwidth networks. Collaborating with Facebook and Google to

get system-level requirements, they developed three generations of switches. Their Helios design was commercialized by their industry partners Calient, Plexxi, and Polatis. Calient has shipped over 1 million ports, and Plexxi and Polatis were acquired by Hewlett Packard Enterprise and Huber+Suner, respectively. As the volume of online users of cloud-based platforms continues to grow exponentially, ERC-inspired advances such as these that make communications faster and more robust have greater and greater impact.

Mobile Devices and Other Electronics

NSF ERCs have had a significant impact on the development of mobile devices, enabling them to become smaller, faster, and better-performing overall.

The Colorado State University-led NSF ERC for Extreme Ultraviolet Science and Technology (NSF EUV) (2003-2013) developed the EUV lasers required for increasing the lithography resolution for microelectronics, revolutionizing the industry. Adopted by the Dutch multinational ASML through

Figure 5: Futuristic digital circuit board by Lamina Akulova, Dreamstime.com

the acquisition of Cymer, an NSF EUV industry member and licensee of its technology, this technology is increasingly enabling advances not only in mobile devices but also in computing architectures, artificial intelligence (AI), nanotechnology, data and energy storage devices, and medical diagnostics.

The Georgia Tech-led 3D Systems Packaging Research Center NSF ERC (NSF PRC) (1995-2006) — still going strong after 32 years — developed the system-on-a-package (SOP) manufacturing process that integrates multiple components in a single package, leading to miniaturization, increased performance, and lower power consumption of electronics. *The technology was widely adopted by the mid-2000s by major players like Philips, Intel, Samsung, and Motorola, and is used especially in products with space constraints such as mobile devices.*

The Virginia Tech-led Center for Power Electronics Systems NSF ERC (NSF CPES) (1998-2008) developed an efficient power-management solution for high-speed microprocessors that enables higher speeds and reduced heat generation. It became the *standard of practice for high-end central processing units (CPUs) and servers in data centers.*

The University of Michigan-led NSF Center for Wireless Integrated MicroSensing and Systems (NSF WIMS) (2000-2010) focused on miniature low-cost integrated microsystems. *Mobius Microsystems, a startup by an NSF WIMS graduate student, applied the technology to improve silicon clocks — timing devices used in any application where a reliable time base is necessary, such as cell phones, USB ports, and communication networks.* The company became a leader in this field and was acquired in 2010 by Integrated Device Technology, Inc. (IDT), which is now part of the Japanese Renesas Electronics Corporation, one of the leaders in the microcontrollers and microprocessors industry.

Advanced Mobile Digital Images

Digital cameras produced better images as time progressed, due in part to improved autofocus. An enabler of this advance was the University of Colorado-led NSF ERC Optoelectronics Computing Systems Center (NSF OCS) (1987-1998) fast aberration-correcting technology that reduced system size, weight, and cost. *The technology was commercialized by CDM Optics, which was acquired by OmniVision Technologies, and since then merged with other companies to become OmniVision.*

Robotic Vacuum Cleaners and Fingerprint Readings

The Caltech-led NSF Center for Neuromorphic Systems Engineering (NSF CNSE) ERC (1995-2005), which focused on developing technologies to enable machines that mimic the human sensory systems, was prolific in startups. Two well-known applications stand out.

Evolution Robotics, a CNSE startup, developed computer vision and autonomous navigation systems that were applied to cleaning robots. *Their first robot was Mint, a robot that dusted and mopped hard surface floors. In 2012 the company was acquired by iRobot, the makers of the well-known Roomba, the automated vacuum cleaning robot*, and Mint was rebranded as Braava. Since 2022, it has been part of the Roomba Combo, which combines vacuum and mopping capabilities.

Figure 7: Cleaning robot --from Wikipedia (https://bit.ly/3Chsn9b)

Figure 8: Digital Persona-inspired fingerprint reader (Credit: CNSE final report, 2015)

Digital Persona, another CNSE startup, developed fingerprint biometric hardware and software that in 2004 were integrated into Microsoft devices. In 2014, the company was acquired by Crossmatch, a leading provider of biometric livescan solutions, now a division of HID Global, and the technology continues to be part of their physical identity and access management software. In 2019, for instance, the Crossmatch fingerprint reader technology was integrated into the Lenovo ThinkPad T490 Healthcare Edition.

Medicine and Health

Figure 9: The da Vinci surgical robot (Credit: therobotreport.com)

Minimally invasive surgery has improved the quality of life of millions of patients by enabling better outcomes, less scarring, reduced pain, shorter recovery time, and fewer complications. The dominant player in the field, *the da Vinci robotic surgical system from Intuitive, incorporates technology from the Johns Hopkins-based NSF Center for Computer-Integrated Surgical Systems and Technology (NSF CISST ERC) (1998-2008).*

The system translates a surgeon's hand movements in real time to the surgical instruments inside the patient's body and displays for the surgeon a high-definition 3D video of what is happening at the surgical site. The da Vinci system is used in a wide range of conditions, including urologic, cardiac, gynecologic, pediatric, head and neck, general surgery, as well as lung biopsy. Through 2022, there were 8,600 da Vinci systems in use in 71 countries, with over 14 million procedures performed.

3D Mammography

Figure 10: (Credit: Northeastern University College of Engineering)

3D mammography is now in widespread use, with 91% of clinical facilities having at least one system and, overall, 48% of mammography machines being 3D. Its widespread adoption is due to *improved imaging technology that reduces the number of false positives and lowers cost*. The technology behind it is Digital Breast Tomosynthesis (DBT), developed by Massachusetts General Hospital (MGH) and General Electric (GE). The Northeastern University-led Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS), a graduated NSF ERC (2000-2010), *solved the major bottleneck to the use of DBT: the longtime needed to reconstruct the image from the raw data*. The center researchers developed a parallelized version of the reconstruction algorithm that reduced execution time from 4 hours to 5 minutes. The center's industrial partner Hologic markets the mammography systems based on DBT technology as SeleniaDimensions, and GE as SenoClaire.

Defibrillators

Defibrillators are medical devices that save lives by restoring normal heartbeat. External defibrillators are commonly seen in public places and are used to revive people experiencing sudden cardiac arrest. Implantable or wearable defibrillators are miniature versions surgically implanted in the chest or worn attached to the chest that automatically detect and treat ongoing irregular heartbeats.

These devices all work by applying an electric charge to the chest to shock the heart into beating normally. Invented in the 1930s, today's defibrillators are more effective, use less energy, and result in fewer side effects.

A significant contribution to their development came from the technologies developed by Duke University-led NSF ERC for Emerging Cardiovascular Technologies (NSF ERC ECT) (1987-1998). The center developed *improved electrodes and biphasic waveforms which made possible portable and improved defibrillators*. The

technology was further developed and taken to market by the center's licensee Medtronic, as well as by the NSF ERC ECT startup Ventritex, which was acquired by St. Jude Medical. *About 200,000 automated external defibrillators (AEDs) and 150,000 implantable defibrillators are sold or implanted annually in the U.S.*

Figure 11:(Photo Credit: National Science Foundation)

Neuroelectronic Implants for Parkinson's Disease and other Neurological Conditions

According to the World Health Organization, as of 2019 Parkinson's Disease affects over 8.5 million individuals, a doubling of the numbers 25 years ago. The disease, a neurodegenerative condition, manifests in motor function impediments, such as slow and imbalanced movement, tremors, and rigidity, as well as in other complications such as cognitive impairment, mental health disorders, and other sensory problems.

Figure 12: Neuroelectronic Implant (from NIH website https://bit.ly/4h3EIwX)

In addition, another neurological condition, essential tremors, affects about 5 percent of the population over 65 — so as the current population ages, the number of people affected is going to increase drastically.
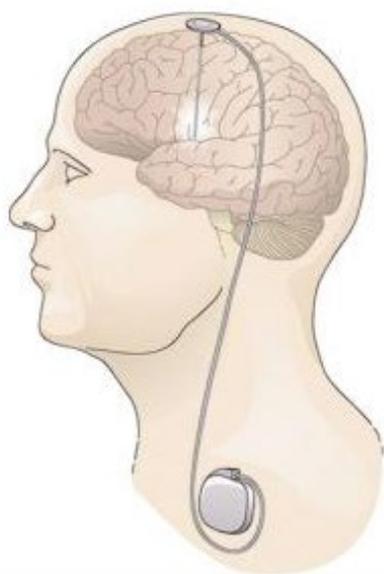
Parkinson's disease is treated with medication that diminishes some symptoms but not others, like tremors. Also, even in situations where medication helps, often the symptoms come and go in an unpredictable fashion; and with disease progression, medication stops being effective. Continuous deep brain stimulation (DBS) of the thalamus via an implantable device was proven to be an effective treatment when medication stops working. The surgeon implants electrodes into the brain and connects them to a small electrical device implanted in the chest. Pioneered by Medtronic, this device was approved by the FDA in 2017 for use in severe cases, and in 2002 expanded for general treatment of Parkinson's disease, essential tremors, and other movement disorders. A second generation of DBS was developed by a collaboration between the University of Washington-led NSF Center for Neurotechnology (NSF CNT) ERC (2011-2023) and Medtronic. The improved technology included biomechanical feedback from the patient's body to deliver the electrical signals only when they are needed, thus maximizing therapeutic benefits, minimizing side effects, and prolonging battery life. By 2020 all Medtronic DBS systems have incorporated the new technology. *Medtronic data shows that in that year over 180,000 patients used DBS in 70 countries.*

It is worth noting that such rapid success and technology translation into products could not have been possible by either a company or a university alone. It was the ecosystem developed under the ERC umbrella that made this happen. Medtronic provided the academic research team with a prototype implantable device which was used for clinical trials, allowing optimization of the parameters and the protocol. Once

the device was refined, it was only Medtronic that had the resources needed to take it through the FDA approval process.

Therapeutic Drug Development

The MIT-led NSF Biotechnology Process Engineering Center (NSF BPEC) (1985-2005) pioneered an interdisciplinary approach to integrating molecular and cell biology with process engineering, with the goal of creating advanced biological technologies. Throughout its 20-year history as an ERC, its primary research focus evolved from therapeutic protein biotechnology to therapeutic gene biotechnology. In addition to the development of technologies leading to bioprocess simulations, algorithms and methodologies for characterization of proteins that help maintain quality during manufacturing, probably its biggest impact was in the hundreds of students it trained in this incipient field, who then occupied prominent positions in nearly all major biopharmaceutical company, such as Genentech, Amgen, and Biogen-IDEC, and also at many pharmaceutical companies, such as Merck, Wyeth, and Bristol Myers Squibb.

Perhaps the most notable alum is Noubar Afeyan, the co-founder of Moderna, the company that developed one of the mRNA vaccines against COVID-19. Afeyan was the first PhD graduate in bioengineering from MIT's NSF BPEC, at the time, the only institution that offered that degree. Initially he started a company for protein analysis that later merged with PE Corporation (now Applera Corporation), the biotechnology arm of Perkin-Elmer Corp. While VP there, he established Celera Corporation, the first private entity to sequence the human genome.

The most notable alum is Noubar Afeyan, the co-founder of Moderna, the company that developed one of the mRNA vaccines against COVID-19.

Other NSF BPEC alumni at GenenTech (now Roche) played key roles in bringing to market monoclonal-antibody-based drugs for lymphoma, autoimmune disorders, and various types of cancers. BPEC alumni at Merck played key roles in the global battle against AIDS, identifying chemicals that could disrupt the function of the AIDS virus, and initiating the current protease-inhibitor drugs used to combat HIV.

Advanced Manufacturing of Pharmaceuticals

NSF ERCs also made significant contributions in developing manufacturing technologies that led to cheaper and more effective treatment drugs.

The University of Florida-led NSF Particle Engineering Research Center (NSF PERC) (1995-2005) helped advance the state of the art of extended-release drugs, which have many therapeutic benefits, including improved safety, compliance, and outcomes at lower cost. They developed the necessary coating technology to allow slow release of the active component. The technology was commercialized by Nanotherapeutics, a company started in 1999 by one of the center's graduate students. Supported by federal contracts, it focused on prophylaxis and treatment of bioterrorism agents. The company changed its name to Ology Bioservices, Inc., and was acquired by National Resilience, Inc., a private biomanufacturing company that develops complex medicines.

Rutgers University-led NSF ERC for Structured Organic Particulate Systems (NSF C-SOPS) (2006-2017) pioneered continuous manufacturing of tablet-form pharmaceuticals. Compared to batch manufacturing, this technology *increases efficiency, decreases cost, and improves overall supply chain efficiency*. Two NSF C-SOPS members, Vertex Pharmaceuticals, Inc., and Johnson & Johnson (J&J), integrated C-SOPS continuous manufacturing technology into their production lines in 2011. In 2015 Vertex received FDA approval to use continuous manufacturing for Orkambi, a cystic fibrosis therapy. In 2016, one of J&J's companies, Janssen Supply Chain (JSC), received FDA approval to use continuous manufacturing for its HIV treatment Prezista. In 2019, the FDA endorsed continuous manufacturing to speed production and improve quality of products across the pharmaceutical industry. Since then, pharmaceutical giants including Pfizer, Eli Lilly, and GlaxoSmithKline have incorporated continuous manufacturing into their operations.

Malaria Drugs

Malaria is one of the most severe public health problems worldwide. In many of the countries affected it is the leading cause of death. In 2022 roughly 249 million malaria cases occurred worldwide, leading to more than 600,000 deaths, mostly among young children in sub-Saharan Africa, The most effective malaria medication is Artemisinin-based combination therapy (ACT). A key ingredient in Artemisinin is

Figure 13: Malaria-carrying mosquito (royalty-free image from Pexels)

artemisinic acid, derived from the leaves of the Artemisia annual plant. The extraction process is complex, has low yield, and involves large volumes of solvents that can be environmentally harmful.

The UC Berkeley-led NSF Synthetic Biology ERC (NSF SynBERC) (2006-2016) developed a process to create synthetic bioidentical artemisinic acid from sugar cane fermentation. In 2013, Sanofi, a global healthcare company, began production of the first semi-synthetic version of artemisinin based on the SunBERC technology, and *within one year, more than 16 million anti-malarial treatments derived from production were supplied to endemic countries in Africa, leading to Sanofi receiving in 2015 the "Patent for Humanity" award from the White House.*

Digital Health

Texas A&M University-led NSF ERC for Precise Advanced Technologies and Health Systems for Underserved Populations (NSF PATHS-UP) (2017-present) has the mission to *develop low-cost Point-of-Care (POC) technologies, initially for diabetes and cardiovascular disease, conditions that are disproportionately present in underserved communities*. Important factors they consider in technological development are

Figure 14: Paths-UP ERC (Credit: Texas A&M University)

skin color, obesity, and other genetic and health factors of target populations. In addition, the center hosts regular seminars and podcasts, summits, and conferences. For example, with funding from major hospitals they hold large workshops that bring together clinicians, medical device companies, and representatives

from government agencies leading to important discussions that help shape the emerging field of digital health.

Entertainment and Multimedia

Digital Video

Watching, creating, streaming, and sending videos on mobile devices is ubiquitous today. Almost everyone in the U.S. is familiar with video files in the MP4 format, which provides a good balance between high-quality images and small file size and is widely used for streaming, downloading, and sharing multimedia content.

This format is a type of file that serves as a digital container of audio, video, subtitles, and meta data. The primary technology behind it is the MPEG-4 video and audio compression standard. A main building-block for MPEG-4 was the MPEG-2 standard, which was the first one resulting in high-definition videos. Research carried out at the Columbia University-led NSF Center for Telecommunications Research (NSF CTR) ERC (1985-1997) was at the heart of the MPEG-2 standard. More than 40 patents went into defining that standard, and Columbia University was the only academic institution among more than a dozen patent holders, along with several major consumer electronics companies.

The MPEG-2 standard is still used today for DVDs and standard, over-the-air TV broadcasting as well as direct-broadcast satellite TV systems. Many countries in the world still rely on this 20-year-old technology.
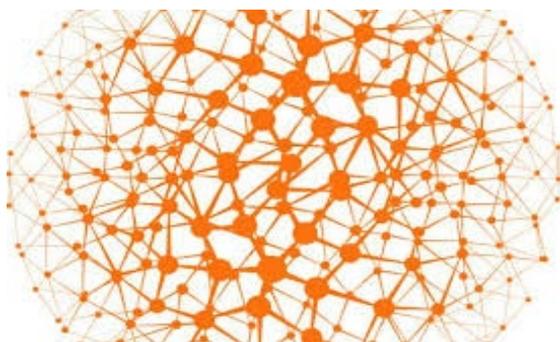

Figure 15: (Credit: University of Southern California)

Cinematic Special Effects

Spectacular special effects are almost expected in action and animated films today. The University of Southern California-led NSF Integrated Media Systems Center (NSF IMSC) (1996-2008) developed cutting-edge visual special-effects technology that ultimately was used in popular movies that won awards. For example, *the visual effects in The Golden Compass and Life of Pi, both of which won Academy Award for Best Visual Effects, were created by Rhythm & Hues Studios based on ERC technology.*

3D Cinema

Most major movie theater chains have auditoriums in which they screen 3D movies. The majority rely on RealD 3D technology. **Movies like *Chicken Little, Avatar, Wicked, and Moana I and II* are just a few popular movies filmed using this technology.**

The core of the 3D technology came from Colorlink, a startup out of the University of Colorado-led NSF ERC Optoelectronics Computing Systems Center (NSF OCS) (1987-1998), which RealD acquired. ColorLink's NSF OCS-inspired research has been a win for RealD; in 2024, RealD claimed to have the world's largest 3D

cinema platform with over 30,000 screens in 75 countries, and with more than two billion people having seen a movie in RealD 3D.

Surround-Sound in Home Theaters and Beyond

Audyssey Laboratories, which began as a startup from the University of Southern California-led NSF Integrated Media Systems Center (NSF IMSC) (1996-2008) helped revolutionize home theater capabilities by addressing the negative effects of room acoustics on sound reproduction. Since then, the company has developed technology for other settings, improving the quality of life of billions of people through its extensive licensing agreements with automakers, professional studios, consumer electronics, mobile devices, and movie theaters.

PATH FORWARD

For four decades, NSF's Engineering Research Centers have exemplified the transformative impact of strategic, policy guided investments in interdisciplinary research, education and innovation. By integrating academia, industry, government and communities, ERCs have driven technological breakthroughs, strengthened the STEM workforce and delivered measurable economic and societal value, advancing the U.S. global competitiveness.

As the nation faces increasingly complex challenges and opportunities from emerging technologies and resilient infrastructure to equitable access and regional innovation, the ERC model offers a proven framework for aligning research with national priorities. Continued investment in and evolution of this model will be essential to shaping the future of engineering innovation, accelerating technology adoption, and ensuring that the benefits of scientific progress are widely shared.

U.S. National Science Foundation