**Validation of ERC Construct Through Surviving Graduation or Early Termination**

From the earliest years of the program, NSF’s ERC Program management saw as one of their major goals positioning the centers to continue in operation after the 10-year period of NSF funding had ended. After the sixth-year of the Program, from the early 1990s on, Workshops on “self-sufficiency” were held during nearly every ERC Program annual meeting. Attaining self-sufficiency after the center had “graduated” from NSF funding was seen as a challenge because it meant that these entities, which in many ways went against the grain of the academic status quo, would need to rely not only on continuing university support but, even more importantly, on the support of their industry base and other government research programs. Even more challenging was maintaining many of the key features of an ERC in the absence of what could be seen as “NSF life support.” At the very least, the loss of the special imprimatur of being an NSF ERC could be expected to have an effect on a center’s chances of survival.

However, these fears might have been unfounded because in 2019, 83% of the 47 graduated ERCs still existed as self-sustaining centers; and as a 2010 report of graduated centers described, many of these centers kept most of their ERC-like features intact.[[1]](#footnote-1) Even some of those centers that were terminated early from NSF support continue to survive as centers today. This appears to be a strong validation of the ERC construct.

Some case studies will serve to illustrate the variety of routes that graduated centers have taken to become self-sustaining. In self-sufficient mode, these former ERCs tend to take one of four different modes:

Type A: A central unit with subsidiary units

Type B: Consortium of member centers

Type C: Single unit but with modified mission and profile

Type D: Center continues with mission essentially unchanged.

***Graduated-ERC Case Studies***

The Systems Research Center Becomes the Institute for Systems Research *(Type A)*

The Systems Research Center (SRC), now the Institute for Systems Research (ISR), at the University of Maryland College Park (UMD) and Harvard University, was initiated in 1985 as one of the first six ERCs. The SRC was founded as a multidisciplinary, two-university, industry-university-government research and education center of excellence to lead in developing the foundations of systems science and systems synthesis and its applications to areas ranging from manufacturing systems to signal processing, chemical process design and control, communication and information networks, robotics, and microelectronics design and manufacturing, to list a few of the initial thrusts.

The SRC received NSF funding in the period 1985-1998 (two rounds, with the second being for 5 years). The most critical step toward becoming a self-sustaining ERC was the case made in 1987–1988 to the State of Maryland, with strong support from industry leaders, to receive permanent funding and become a cross-disciplinary UMD Institute. The key argument made was the impact of SRC/ISR programs on the State’s economic development. This effort succeeded. In 1989, Maryland appropriated permanent state funding to the SRC/ISR at $3M/year, progressively implemented. In 1992 the ERC became a permanent cross-disciplinary unit of UMD, renamed the Institute for Systems Research. The ISR is currently the longest-running self-sustained NSF ERC (33 years total as of 2018). Another important factor was the careful implementation, during 1988-1991, of the organizational, financial, industrial collaboration, and academic structures, which are still operating on this original foundation, with minor tuning. Key components of the structure were the following: joint faculty appointments (about 40, 3-year renewable); 30,000 sq. feet of contiguous space; 6 Constituent (group) Laboratories; and excellent administrative and technical support staff. The ISR has used this superb infrastructure to create many cross-disciplinary centers within its umbrella—such as the very successful Maryland Hybrid Networks Center (HyNet), which through close collaboration with industry created a new industry sector, “Internet over satellite systems and services.”

The ISR also developed innovative educational programs. In 1986-1987, the offering of Systems Engineering (SE) classes was initiated through a new Master of Science in Systems Engineering (MSSE) program. In 1994-1998, with input from industry, it was transformed into a new quantitative SE curriculum. In 1999-2002, with support from an NSF Research and Curriculum Development grant and industry, three new and very strong core courses on SE foundations were developed. In 2006-2007, the MSSE was restructured with help from industry and continues today.

Critical to ISR becoming a self-sustained ERC was the early emphasis on the long term (the systems synthesis theme and becoming self-supporting) and on the balance between short-term and long-term research. When NSF funding ended in 1998, two major challenges surfaced. The first was sustaining a systems focus in most projects; the ISR no longer had large, central, self-directed funds for its long-range systems synthesis research. The second was expanding the industry sponsors and collaboration. Both challenges were met by creating smaller centers, as spokes nurtured by the core systems focus of ISR and its faculty and by winning large projects like Multidisciplinary University Initiatives (MURIs) and the Army Research Laboratory Collaborative Technology Alliances. There was a shift in industry support, whereby more projects now had a narrower focus and a short-range research outlook. The smaller centers and industry funding helped with sustainability, but they also added constraints. Additionally, two centrally funded ISR programs ended: the ISR Fellows program that helped recruit some truly outstanding graduate students and the ISR Postdoctoral Fellows program that brought many young scientists to the ISR to be mentored and contribute to its programs. Nevertheless, the State support and the organizational structure as a permanent Institute maintained the high visibility of the ISR internationally and faculty, students, and postdoctoral researchers both from UMD and externally continued to actively seek ISR affiliation.

The future for the ISR is particularly promising due to the increasing importance of systems thinking and synthesis in so many areas, from engineering, to the internet, to the economy, to health care. Indeed, the synthesis of complex engineered and other systems from components and the associated education needs represent the next frontier in engineering research and education.

From CCFS to HPC2 at Mississippi State[[2]](#footnote-2) *(Type B)*

The ERC for Computational Field Simulation (CCFS) at Mississippi State University was initiated in 1990 as a multidisciplinary academic research center with a mission to reduce the time and cost of complex field simulations for engineering analysis and design through cross-disciplinary research teams and by utilizing testbed integrated systems to provide common focus. Science and engineering faculty from Aerospace Engineering, Chemical Engineering, Computer Science, Electrical and Computer Engineering, Mathematics, Mechanical Engineering, and Physics provided expertise for different components from which to build the integrated systems. The ERC’s vision was to give U.S. industry and government agencies access to superior capabilities for computational field simulations of large-scale geometrically complex physical field problems through domain-specific integrated simulation environments for rapid analysis and design. This approach sparked a shift from physical prototyping toward computational simulation prototyping.

A major application emphasis of the ERC was in compressible and incompressible computational fluid dynamics to provide the means to simulate complete real-world applications, such as cruise missiles, biofluid flow with particulates, rocket exhaust, and weapon or stage separation. However, the Center’s strategic research efforts in building computational problem-solving environments encompassed many areas of field physics, including extensions into diverse, very complex multidisciplinary applications that were and remain relevant to industry and government agencies.

The fulfillment of the Center’s mission was illustrated by the ERC’s ability to simulate in real time the reentry of John Glenn’s Discovery space shuttle flight after the orbiter drag chute door was lost during main engine startup. NASA engineers wanted to know the dynamic pressure in the region of the missing chute door to estimate the aerodynamic loadings during reentry. ERC researchers read a previously supplied space shuttle orbiter geometry into the ERC’s integrated simulation environment, created the grids within hours, and computed the initial simulation results within two days. This successful effort demonstrated that the ERC could take a complex, real-world problem and compute the solutions in two to three days after receiving the geometry description, an achievement that was a direct result of the ERC’s mission and vision—and the commitment of its team.

Graduating from the NSF ERC Program support in 2001, the Center continued (then and now) in an expanded mode as the self-sufficient High Performance Computing Collaboratory (HPC²) that was formed in 2003 with funding from a range of federal agencies and industry. The transition from an ERC to successful self-sufficiency took place over a two-year period following graduation. The first realization was that, with multiple sources of funding directed at specific research efforts, the ERC model—with its balanced emphasis on research, education, and industrial collaboration—could not be sustained. The second realization was that the success of the ERC enabled a significant broadening of the scope of research effort related to HPC, and thus a significant widening of the range of funding sources. The third realization was that the ERC had developed very strong individual leaders who could function best, given this broadening of scope, in a collaborative effort of individual entities.

There was a strong desire within the university to retain the ERC brand name, and Center directors initially planned to maintain a single-center type of organization with a much broader scope and a continued common theme of computational science and engineering using HPC. However, that concept evolved into a consortium of centers focused on interdisciplinary research in computational science and engineering, using HPC as a more viable operational mode, which allowed the separate centers to operate more efficiently while still maintaining HPC²’s stature as a single entity. The member centers that comprise HPC² share: (1) a common core objective of advancing the state of the art in computational science and engineering using high-performance computing; (2) a common approach to research that embraces a multidisciplinary, team-oriented concept; and (3) a commitment to a full partnership between education, research, and service.

The focal areas and centers currently residing as members of the HPC2 include: biocomputing—Institute for Genomics, Biocomputing and Biotechnology; geospatial—Geosystems Research Institute; an FAA-funded unmanned aircraft center—Alliance for System Safety for UAS through Research Excellence (ASSURE); advanced vehicles—Center for Advanced Vehicular Systems (CAVS); fundamental sciences—Center for Computational Science; cyber-security—Center for Cyber Innovation; and a NOAA-funded cooperative institute—Northern Gulf Institute. Directors of these centers collectively form an operations board to oversee central operations of the HPC2, and they advise the director of HPC operations on new purchases and strategic initiatives.

There has been significant broadening of the breadth and disciplinary composition of participating faculty commensurate with the expansion of scope of effort since graduation. The common theme of computational science and engineering utilizing HPC that is the legacy of the NSF ERC now features faculty from every college at Mississippi State.

At the time of graduation from the ERC program, the center’s budget was roughly $17 million. Today (September 2018), the High Performance Computing Collaboratory’s total budget is over $55 million—more than one-third of the university’s entire funded research. Since graduation, the HPC2 centers have generated over $600 million in research funding. The total number of people involved in the Center has grown from 245 to 486. MSU has had a computing system in the Top 500 for most of the semi-annual lists published over the past 20 years. In addition, the impact of the ERC through generating accomplished high-performance computing researchers has received national attention, with former students and faculty holding prestigious positions at universities and government agencies throughout the country.

In 2002, the presence and prestige of the ERC was instrumental in the State of Mississippi’s successful effort to attract the then-largest Nissan manufacturing plant in North America. As a result, CAVS was created by special legislation that funded a 57,000-square-foot research facility on the MSU campus in Starkville, and a 25,000-square-foot CAVS Extension Center adjacent to the Nissan plant in metro Jackson. The original ERC facility in the Thad Cochran Research, Technology and Economic Development Park was also expanded to a total of 71,000 square feet.

Independent assessment by the U.S. Department of Commerce indicated that just one of the HPC2 units, CAVS Extension, has had over $5.9 billion in economic impact on the U.S. economy, and has assisted in creating or retaining 4,753 jobs in Mississippi over the past 12 years. Additionally, the Center has helped industry create $44.5 million in cost savings and has led to over $200 million in plant and equipment investments over the same period.

HPC2 is a leader in efforts to recruit companies to Mississippi, as well as assisting in the creation of innovative startup companies. The computational capabilities of HPC2 have been showcased by the Mississippi Development Authority during the recruitment of several companies that ultimately located in the state, such as Paccar, Steel Dynamics, and Toyota. The university has maintained relationships with each of these companies and continues to partner with them in multiple projects to this day. Companies such as II-VI Inc., nCode, Babel Street, and Horne Cyber have roots to the HPC2. These companies have taken the results of work performed through the center and used the intellectual property generated from research to create homegrown technology companies that are now creating high-paying jobs in the state.

In the January 1999 issue of *ASEE Prism*, the director of the National Science Foundation cited the ERC at Mississippi State as a prime example of a successful NSF ERC, noting that this ERC “effectively demonstrates that you can institute change in a very positive way.” Without question, the Center did bring major change to MSU, most notably by establishing a pattern of highly interdisciplinary research, the platform upon which HPC2 is built. The ERC also established a new multidisciplinary graduate program in Computational Engineering, cutting across engineering, computer science, and art. Along with the Department of Art and the School of Architecture, the ERC facilitated new graduate degrees in animation and electronic visualization: a Master of Fine Arts in Art and a Master of Science in Architecture in Electronic Design.

Particle Engineering Research Center (PERC) *(Type C)*

The Particle Engineering Research Center was established at the University of Florida (UF) in 1994 as the “NSF Engineering Research Center for Particle Science and Technology (CPST).” The mandate for the Center was to conduct industry-relevant research in this area. From its inception, the Center has served as a catalyst for synergistic interdisciplinary collaborations that have led to well over $50M invested in cutting-edge research, the education of more than 1000 students, fruitful collaborations with over 100 companies, and the successful transfer of numerous particle-based technologies. In 1997, the Center moved into the newly-constructed Particle Science and Technology Building, funded by the State of Florida as a testament to its commitment to this enterprise. The CPST was one of the very few NSF ERCs for which the host university built a separate building completely dedicated to the Center.

In 2001, the Center was renamed the Particle Engineering Research Center (PERC); the Characterization Research Instrumentation and Testbed (CRIT) facility became the PERC R&D Facility and was made a UF auxiliary in the summer of 2004. With the impending successful completion of the NSF funding cycle, the PERC “Service Center” began charging fees for usage of equipment and technical staff time to help offset costs. This was part of the Center’s self-sufficiency plan for post-NSF operations.

Also part of the self-sufficiency plan was the strategic evolution of the Center’s original research scope to update how the Center addressed societal and industrial needs. In the early years the Center focused on four thrust areas: (1) online analytical systems, (2) concentrated particulate dispersions, (3) transport and handling, and (4) treatment of particulate effluents. A major shift in the research focus took place in 2000 with a new research focus on Nano-Bio Systems. This change in direction was sparked by increasing national and international interest in nano- and biotechnologies and the realization that particle-based nanotechnologies would play a significant role in these emerging fields.

In 2007, PERC team members, in collaboration with other faculty researchers, were awarded a State of Florida Center of Excellence grant, “Center for Nano-Bio Sensors,” for translational technology developments focused on sensors for healthcare and homeland security applications. In 2008, PERC researchers joined hands with their counterparts at Columbia University and were successful in establishing a joint NSF I/UCRC (Industry University Cooperative Center), “Center for Particulate and Surfactant Systems.” These evolutions have proven to be instrumental in the long-term survival of the Center.

After successfully graduating from the NSF ERC program, while the loss of NSF funding was certainly felt, PERC nevertheless continued on its path of success. PERC now relies upon federal, state, and industry grants, its industry partners, and the Service Center to generate the research and operational funds necessary to maintain a healthy research program. In June 2008 the Center held a two-day retreat to address this issue, re-evaluate itself, and develop a new vision and strategic plan to propel PERC into the future. PERC’s next-generation vision is to “Innovate and transform particle science and technology advances into useful applications for sustained societal well-being.”

The ERC’s Industry program began with commitment from 25 members comprised of large and small companies. Over the ensuing 11 years of the NSF center grant, the research program continuously evolved according to the needs of the students, faculty, and the Center's industry partners. Industry membership rose from 25 to a high of about 50 participating companies, finally settling at an equilibrium level of about 40 companies, where it remains today.

PERC aspires to maintain its leadership in the broad field of particle science and technology by enhancing the Center’s activities in translational research and technology transfer to carry out its mission, “to better serve society through education, innovation and advancement of particle science and technology.”

CIE to IPrime *(Type C)*

In 1988 the NSF established an ERC at the University of Minnesota called the Center for Interfacial Engineering (CIE). This ERC took advantage of the expertise of leading faculty members to establish a new subfield called interfacial engineering. The CIE had a positive impact on multidisciplinary research and graduate education and was instrumental in establishing the University of Minnesota Characterization facility. An important element of the Center was a robust industrial outreach program. The CIE operated until 1999, when the mandatory eleven-year funding expired. In the tenth year, when CIE funding was in sunset, faculty and many of the charter industrial members (e.g., Kodak, Dupont, and 3M) agreed that the collaboration in CIE had been very valuable for both parties and pushed for the establishment of a new center to promote industrial interactions.

As a result of the strong industrial interest, IPRIME (The Industrial Partnership for Research in Interfacial and Materials Engineering) was created, not only to maintain the collaborative research already underway but also to extend the partnership to other programs, including those supported by the Materials Research Science and Engineering Center (MRSEC) established in 1998 under an NSF grant. The CIE had fostered a culture of integrated research, education, and industrial interaction that continues today in both IPRIME and the MRSEC.

IPRIME focuses on materials, devices, and processes. Offering a “one-stop-shop” for industry, the consortium provides an entry point for industrial connections to University of Minnesota research. Companies pay annual membership dues that support collaborative, open-literature research with university faculty and participate in IPRIME activities. There are three levels of membership: Sponsor, Affiliate and Small-Company. IPRIME is self-supporting, with more than 35 industrial companies.

IPRIME research is divided into eight research-programs. Each research program is led by a faculty program leader and can have as many as ten principal and associated investigators. Sponsor members can participate in up to four of these eight research programs. Affiliate and Small-Company members can participate in only one program. The larger research programs each have a Technical Advisory Committee (TAC), which provides industrial feedback on the research. Through TAC participation companies can influence the direction of IPRIME research.

IPRIME membership is quite diverse and includes many blue-chip international companies such as ExxonMobil, Boston Scientific, and Corning, but also includes smaller rapidly growing companies like SurModics and Bedford Industries.

Unlike typical contract university research, where companies can tightly protect their intellectual property, the research in IPRIME is non-proprietary, with a focus on collaborative two-way knowledge transfer. Company members must anticipate and accept that joint research will be published in the open literature.

IPRIME research can also be described as “pre-competitive” in nature. The term accurately captures the fact that IPRIME’s fundamental research is conducted well before specific product ideas are reduced to practice. Many industrial companies (even many high technology companies) work from only an empirical understanding of their materials and processes. To more effectively introduce truly disruptive (step-change) technologies, companies strive to understand the scientific fundamentals of their current technology.

The opportunity to delve into the fundamental science that undergirds a company’s products and technology is the basic service that IPRIME provides. Even for companies participating in the most commoditized markets, there are fundamental problems which companies don’t have either the time or the capability to investigate. IPRIME membership appeals to companies that are looking to do the fundamental work externally that they don’t have the time, capability, or inclination to do internally.

***Kansas ERC Thrives on Its Own After 5 Years of NSF Support* (Type D)**

The examples above indicate how the ERC construct has spawned innovations in technology and new fields of engineering, and resulted in a more collaborative culture across the disciplines and between academic and industrial engineering. These impacts came from over 60 ERCs that received 10-11 years of NSF support. The question that remains is: Can an ERC that fails to gain renewal survive and continue to function in an ERC-like mode? There have been nine ERCs that failed to gain a renewal recommendation after their third-year renewal reviews. Most disbanded after the end of the five-year agreement with NSF, but one is noteworthy for its continued operation in an ERC-like mode.

The Center for Environmentally Beneficial Catalysis (CEBC), headquartered at the University of Kansas, Lawrence, not only survived after the five-year ERC award ended, it continues to thrive. Led by Bala Subramaniam, a Professor of Chemical Engineering, the ERC award funded research from 2003 to 2008. CEBC’s original vision was to develop technologies that would transform the chemical manufacturing industry by designing cleaner, safer, and economically viable catalytic processes. Long-term goals were projected to prevent pollution, conserve resources and eliminate hazards by applying the principles of green chemistry and engineering.

Despite the loss of NSF support for the original ERC, Subramaniam and his team have successfully continued to operate, maintaining all of the original ERC elements: research, industry collaboration, and education. This was enabled by steadfast support from the Industry and Science Advisory Boards. Committed leadership in the University of Kansas administration was also instrumental, resulting in the elevation of CEBC to a KU Center of Excellence and providing ongoing core support. Subramaniam and the CEBC team successfully sought increased industry and other government support to offset the loss of ERC Program support.

In 2008, the CEBC’s final year of ERC funding, the center had $2.9M with $1.7M coming from the ERC Program, $.440M from the state, and $.250M from industry. By 2013, CEBC had garnered $16M from various sources, including:

* $2M from NSF in 2012 to acquire a state-of-the-art 3D scanning electron microscope for catalyst and materials research;
* $4.4M in 2013 to launch a Network for Sustainable Molecular Design and Synthesis program, one of four awards made that year by the NSF and the Environmental Protection Agency;
* $1M from NSF for two Research Experiences for Teachers programs.

In 2018, the center’s external funding was $4.0M, with $2.3M coming from federal sources, $1.2M from industry and $.5 M from University and State sources. Today, the center remains true to its original mission, and continues to invent and innovate in the field of catalysis attracting outstanding faculty and student talent. New faculty recruitments and an expansive infrastructure have helped to diversify the center’s research portfolio to address pressing grand challenges of our time, such as converting biomass and carbon dioxide into valuable products. While the ERC planted the seeds of collaboration, the center continues to reach across disciplines, institutions and even nations to advance its research initiatives. Key achievements include:

* 60+ inventions and patents, and 6 licensed technologies
* 25+ company partners, including nine currently with sustained membership of 3 to 15 years
* 10+ industry-sponsored proprietary projects
* 420+ publications
* 200+ students and researchers trained at the center
* 38 high school teachers engaged in summer research
* 3 Fellows of the National Academy of Inventors
* 3 current NSF CAREER award winners, 5 total
* Winner of the 2010 Kenneth G. Hancock Memorial Award in Green Chemistry presented by the American Chemical Society’s Green Chemistry Institute

One start-up company.

By 2018, the vision of the center was guided by the following questions:

* Can we rationally design **new catalytic materials** that maximize the formation of the desired products (meaning less unwanted byproducts) at mild conditions (less energy use) while being cost effective?
* Can we reduce or **eliminate the use of hazardous materials** in chemical processes, including toxic solvents and corrosive acids?
* Can we come up with a new **energy efficient process scheme** that reduces the number of steps, or avoids energy-intensive separation steps?
* Can we use advanced computer modeling tools to speed-up the discovery process, predict **economic and environmental performance**, and guide researchers toward optimal solutions?[[3]](#footnote-3)
1. Lewis, Courtland S. and James E. Williams, Jr. (2010). Post-Graduation Status of National Science Foundation Engineering Research Centers: Report of a Survey of Graduated ERCs. Melbourne, FL: SciTech Communications, LLC., p. 1. [↑](#footnote-ref-1)
2. Written in collaboration with David Shaw and Don Trotter at the HPC2. [↑](#footnote-ref-2)
3. Written in collaboration with Professor Bala Subramanian, University of Kansas, Lawrence starting from <http://cebc.ku.edu/history-cebc> and http://cebc.ku.edu/discover [↑](#footnote-ref-3)