2022 NSF ERC BIENNIAL MEETING REPORT

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2022 NSF Engineering Research Centers (ERC) Biennial Meeting: Meeting Report

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This meeting report was drafted by Mark Matthews and finalized by Alexandra Sharpe and Erin Steigerwalt. Quality Evaluation Designs oversaw key meeting evaluation activities, including developing and conducting qualitative and quantitative analysis of the meeting, distributing and collecting the post-meeting survey, and composing the meeting evaluation report. The following ASEE staff members contributed to the report by taking notes during meeting sessions: Aqila Coulthurst, Heather Deale, Sarah DeLeeuw, David Scott Mazzeo, and Alexandra Sharpe.

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EXECUTIVE SUMMARY

The 2022 National Science Foundation (NSF) Engineering Research Centers (ERC) Biennial Meeting, held on September 20 – 21, 2022, in Arlington, Virginia, brought together close to 200 attendees representing 22 ERCs for two days of discussions about best practices in research, value creation, innovation, and building an inclusive and diverse workforce. Hosted by the American Society for Engineering Education (ASEE), the meeting marked a resumption of regular biennial gatherings since prior to the COVID-19 pandemic.

The meeting program was comprised of a variety of sessions revolving around the theme of “building communities of innovation,” including keynote, panel, breakout, and poster sessions and various opportunities for networking and collaboration. The meeting also included the popular Perfect Pitch competition, during which ERC undergraduate, master’s, and PhD students succinctly present their research in the context of societal needs and the broader impact of their success. During the meeting, attendees welcomed eight Gen-4 ERCs and celebrated seven graduating ERCs, which had completed 10 years in the program, in a culminating graduation ceremony.

The objectives of the 2022 NSF ERC Biennial Meeting were to: 1) provide attendees with opportunities to network and collaborate with each other to share best practices and develop ongoing communities of practice across ERCs and 2) provide attendees with opportunities to talk with NSF Program Officers in a less formal venue than site visits.

Results from the post-meeting evaluation survey indicated that these objectives were met. As indicated by survey respondents, the most valuable aspect of the meeting was networking, with 88% of respondents “highly valuing” their networking interactions, though they expressed the desire for more organized time to talk with other ERC members holding the same roles as them.

Suggestions for improvement largely fell into two categories: logistics and content. In terms of logistics, respondents rated the venue and food options poorly. In terms of content, concerns focused on keynote speakers taking too much time and breakout sessions being too short and too few, limiting opportunities to network with peers. Respondents identified significant challenges at their ERC that might or might not have been addressed at the meeting. The top five (of 14 total) were: administration and reporting burden, sustainability after graduation, diversity, equity, and inclusion (DEI), ERC teambuilding, and trainee engagement. When asked the extent to which each challenge was addressed at the meeting, answers ranged considerably, with respondents who cited the same challenge varying from *not at all* to *extensively*.

BACKGROUND

Begun in 1984, the ERC program is based on a vision of "strategically planned cross-disciplinary research, strong industrial partnerships, and active involvement of students of all levels" (Preston & Lewis, 2020, In Memoriam…). Operating at the intersection of fundamental research, applied engineering, and technology development, the 79 centers funded since the program started have produced more than 240 companies and 900 patents, and trained more than 14,000 students at the bachelor's, master's, and doctoral levels. The program's emphasis on high-risk, high-payoff research has resulted in an economic impact estimated in the tens of billions of dollars. Preston and Lewis (2020) assert that, of the 47 ERCs that had graduated by 2019, 39 (83 percent) still existed as self-sustaining centers. Substantial funding—up to $50 million per center over 10 years—allows NSF to exert a profound and measurable influence over university culture, policies, and teaching practices. Committed to the Foundation-wide goal of broadening participation in science and engineering, the program also supports Alliances for Graduate Education and the Professoriate (AGEP), which seeks to expand the ranks of underrepresented minority STEM faculty and researchers.

In preparing for the fourth generation of ERCs, NSF drew on recommendations from the 2017 National Academies report, *A New Vision for Center-Based Engineering Research*, which, referencing a 2014 National Research Council report, defined convergence as "a problem solving [approach] that cuts across disciplinary boundaries [and] integrates knowledge, tools, and ways of thinking from [a variety of disciplines] to form a comprehensive synthetic framework for tackling scientific and societal challenges that exist at the interfaces of multiple fields" (p. 21). Convergence stimulates innovation, collaboration, and partnerships—not just across disciplines but across industries and sectors.

Expanding on this definition, the Gen-4 ERC program solicitation states that convergent research approaches require "purposeful team formation… supported by diversity and a culture of inclusion where all participants are recognized and derive mutual benefits" and support research driven by major societal challenges that has the potential for societal impact. (National Science Foundation, n.d.) As noted in NSF's *FY2020 Engineering Research Centers Program Report*, each Gen-4 ERC has "interacting foundational components… beyond the research project, including engineering workforce development at all participant stages, a culture of diversity and inclusion… and value creation within an innovation ecosystem that will outlast the lifetime of the ERC" (p. 63).

The following eight Gen-4 centers were launched in FY2020 and FY2022 and pursue ambitious goals in areas ranging from cryogenics to healthy buildings, quantum networks, transportation, and agriculture: 1) Center for Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE); 2) Center for the Internet of Things for Precision Agriculture (IoT4Ag); 3) Center for Advanced Technologies for Preservation of Biological Systems (ATP-Bio); 4) Center for Quantum Networks (CQN); 5) Center for Smart Streetscapes (CS3); 6) Center for Advancing Sustainable and Distributed Fertilizer Production (CASFER); 7) Center for Hybrid Autonomous Manufacturing Moving from Evolution to Revolution (HAMMER); and 8) Center for Precision Microbiome Engineering (PreMiEr) ("Engineering Research Centers," n.d.). At the time of the 2022 ERC Biennial Meeting, competition was underway for as many as six more ERCs, which NSF expects to announce in summer 2024.

ABOUT THE MEETING

Faculty, staff, and students representing 22 NSF ERCs gathered in Arlington, Virginia, on September 20–21, 2022, for two days of discussions about best practices in research, value creation, innovation, and building an inclusive and diverse workforce. Hosted by the American Society for Engineering Education (ASEE), the meeting marked a resumption of regular biennial gatherings since prior to the COVID-19 pandemic. Close to 200 attendees welcomed eight Gen-4 ERCs and celebrated seven graduating ERCs, which had completed 10 years in the program.

Four keynotes focused the audience on ERC themes: value creation, broadening participation, convergence, breakthrough research that benefits society, and entrepreneurship. Curtis R. Carlson described ways to substantially increase the economic payoff from research. Calvin Mackie spoke about his New Orleans-based STEM NOLA initiative, which has engaged more than 75,000 students in hands-on STEM learning since 2013. Naomi Halas recounted how interdisciplinary research using nanoparticles and photonics led to breakthroughs in prostate cancer therapy, solar-powered water desalination, and a new, cheaper, and environmentally friendly method of hydrogen production. Kamran Elahian combined his own account of audacious moves and lessons learned in building 11 companies and his observations on the innovation economy, which he said is changing industry, government, and academia.

Two panel discussions drew on the experience of ERC veterans and NSF Program Directors. Two breakout sessions provided attendees opportunities to discuss challenges, innovations, and practices in smaller groups, first by ERC role and then by topic of choice.

The Perfect Pitch Competition showcased the entrepreneurial talents of young engineering researchers. The meeting culminated with a reception that featured concluding remarks by NSF Assistant Director of the Directorate for Engineering (ENG) Susan Margulies, a video greeting by NSF Director Sethuraman Panchanathan, announcement of the Perfect Pitch Competition winners, and a graduation ceremony for the seven centers completing their decade with the program. During the ceremony, videos were played touting these centers' successes and, in some cases, hinting at continued operation.

Opening Remarks

Day 1 Opening Remarks

Sandra Cruz-Pol, Program Director, Gen-4 Engineering Research Centers (ERC) and Planning Grants for ERC, *National Science Foundation*

José Zayas-Castro, Engineering Education and Centers (EEC) Division Director, *National Science Foundation*

Susan Margulies, Assistant Director of the Directorate for Engineering (ENG), *National Science Foundation*

Jose Zayas-Castro with a nod to the COVID-19 pandemic that forced a delay of this meeting from 2021 to 2022, gave a shout out to "all the chemical engineers, genetic engineers, and scientists who develop the vaccines and technologies so that we could be here today." Zayas-Castro noted the Gen-4 emphasis on ERC topics with societal impact, but said it was important to recognize that several Gen-3 centers were also pursuing that goal. He also encouraged ERCs moving to a second round of funding, as well as graduating ERCs, to look for opportunities to collaborate with and increase the participation of institutions and regions not typically represented in ERCs.

In her opening remarks, noting that ERCs are considered "the jewel in the crown of the NSF," Susan Margulies urged attendees to share stories of their centers' impact. That way she can "kvell about their successes" and about how the engineering community, in partnership with industry, "is creating new fundamental knowledge in science and in engineering and developing an engineering workforce integrated with a research plan."

But engineers should talk about more than successes, Margulies said. Their field remains "a closely guarded secret," with too little public understanding of what their work entails. "I like to say we need to show our sweat as engineers... Why do we love it? Why do we enjoy that iterative process of discovery, learning—we don't call it failure—and then continually iterating?" Why, she continued, "do we have a mode of teamwork, where we take stakeholder information and use it to identify not the one best path, but several optimal paths that depend on the priorities, and depend on the available resources?"

Margulies reminded her audience that careers continue beyond participation in an ERC. "We believe that an engineering research center is just one step... along your journey, and that you'll continue to flourish beyond graduation."

Keynote Sessions

Amplifying the Impact of ERCs Through Value Creation: Imperative for Achieving Paradigm-Shifting Gains in ERC Performance

Curtis R. Carlson, Distinguished Executive in Residence, *Worcester Polytechnic Institute;* Professor of Practice, *Northeastern University;* former President and CEO, *SRI International*

Curtis Carlson challenged attendees to think about what it would mean if they increased the value of the ERC program by 10 times. This would represent "a paradigm shift," he ventured, but "I think that's possible." When he became CEO of SRI International, formerly the Stanford Research Institute, the firm had been in decline for 20 years and was bankrupt. He proceeded to turn it around. It grew by three and a half times, creating world-changing innovations in high-definition television and satellite broadcasting; Siri, bought by Apple; and Intuitive Surgical, maker of robotic surgery equipment.

A Worcester Polytechnic Institute alumnus with a PhD in engineering from Rutgers University, Carlson heralded the "exponential economy" in a 2006 book, *Innovation: The Five Disciplines for Creating What Customers Want* (co-authored with William Wilmot), arguing that expansion of the knowledge economy, global research and development, and rapid advances in communication technology opened huge opportunities for innovation to spur business growth.

But it turned out that American economic growth has been modest. While the nation faces an urgent need for more researchers, much of those researchers' effort is spent on projects unlikely to find a market or users. Most tech transfer programs at universities lose money; the exceptions are drug inventions that are licensed to manufacturers.

Too often, Carlson said, institutions and companies fail to work on building value. At SRI, the reason was that its people "just weren't working together in a productive way... It's like you've been pushing the wrong button." Rather than pursuing a solution when they first embark on a project, researchers need to experiment, concentrating on the problem they're trying to solve and keeping the end-user in mind. Reframing—approaching the problem from varied angles—was how Rita Colwell, the University of Maryland microbiologist and former NSF director, tackled a cholera epidemic in Bangladesh. Seemingly obvious ways to combat the water-borne

disease wouldn't work in that environment: Boiling water was impractical during flood emergencies and required firewood, which was in short supply; and villagers believed surface water from ponds or streams was better than both chemically treated water and well-water, which too often contained arsenic. The best solution turned out to be sticking with surface water and filtering it with four layers of local cloth. This wasn't ideal, but it cut the cholera death toll by 50 percent.

A tenfold improvement in an ERC's performance starts with consensus around a value proposition. Does the product or prospective research outcome address an important unmet end-user or societal need, as opposed to an interesting research problem? Is their approach to a solution "unique, compelling, and defensible?" Does their model promise end-users a cost-benefit ratio 2 to 10 times better than either the competition or alternate solutions? Carlson gave these questions the label NABC (Need, Approach, Benefits/Costs, Competition). Without a common language, "it becomes really, really hard."

Another big challenge for ERCs is that the varied teams, assembled with different skills and multiple disciplines, can look like a puzzle. Putting the pieces together to synthesize solutions to complex problems is very difficult. One approach to address this challenge is "value creation forums," in which five teams are brought together to work through NABCs and listen to each other's value propositions. They meet every two to four weeks and give each other feedback on what was good and what can be improved in the eyes of the end-user. Videoconferencing has proved to be a collaboration game-changer.

A value-creation approach enabled SRI to coordinate 300 researchers from 25 university and commercial research institutions and develop CALO (Cognitive Assistant that Learns and Organizes), an artificial-intelligence-driven digital device that can be told what to do and learn from experience. CALO produced several major spinoffs, including Siri, acquired by Apple.

Re-Thinking STEM Outreach & Engagement: Building Capacity Through Building Community

Calvin Mackie, President and CEO, *STEM NOLA*

Calvin Mackie's academic career ended when Tulane University, reeling from the effects of Hurricane Katrina, merged science and engineering into a single school and eliminated mechanical engineering. That "turned out to be a blessing in disguise, because that led me to my life's work," Mackie said. His third-grade son provided the impetus for what became STEM NOLA, when he stunned his parents one day when he said he didn't like science. He complained that instead of giving pupils hands-on work, his teacher talked to the blackboard. Mackie proceeded to fill the gap with Saturday science projects in the family's garage. When these grew popular among neighborhood kids, Mackie and his wife, a pharmacist, realized a broader community could benefit.

"STEM Saturdays" and other STEM NOLA events draw 200 to 300 K–12 students at a time to gyms and playing fields outfitted as temporary laboratories. Kids come with their parents, and college-student volunteers guide experiments. At one session, kids dissected a lung, built a mechanical lung, and manipulated a virtual reality lung. At another, held at the riverside University of New Orleans' Lakefront Arena, young students designed, built, and set off rockets. STEM NOLA states that, since 2013, it has engaged more than 75,000 students—mostly low-income and nearly half of them female—in hands-on STEM learning. During the COVID-19 pandemic, the program pivoted to STEM Global, offering virtual projects in five countries. It also offers summer tech camps and a bridge program in Jefferson Parish, outside New Orleans.

A skilled speaker, publicist, social media user, and fundraiser, Mackie has attracted an impressive list of sponsors, from the State of Louisiana and Ochsner Health to the Department of Defense, Boeing, and Chevron. The Kellogg Foundation provided seed money to turn a 42,000-square-foot building, donated by Ochsner Health, into a $10 million STEM innovation hub. Mackie speaks of New Orleans becoming a Wakanda, the technologically advanced fictional nation of the Marvel Black Panther movies.

“Our whole goal has been to lower the barrier to entry for people into STEM,” Mackie told attendees—and the younger they’re exposed to it, the better. A core component of STEM NOLA is that “we center ourselves... in a community. And it prioritizes young people and families.” Mackie asked, “How do we marshal the human capital from our institutions and into communities in an efficient way, so that those kids can touch, feel, and see people and know that [success in STEM] is possible for them?” He contrasted the poor STEM preparation common among low-income students with the fact that, “we live in a nation that made sure that every Black and brown boy touched a football before the age of four.” A university can reject an aspiring engineer with poor test scores from a low-ranked high school, but if a student from the same school is a promising athlete, “they know exactly what to do after school to make sure that kid can graduate,” Mackie said.

Mackie had himself been a basketball star in high school before an injury stopped him from playing. Low SAT scores necessitated remedial reading and developmental mathematics classes at Morehouse College, but the school offered a path forward. Taking advantage of Morehouse’s dual-degree program with Georgia Tech, Mackie graduated with bachelor’s degrees in math and engineering and membership in Phi Beta Kappa. He went on to earn a PhD in mechanical engineering from Georgia Tech.

Innovation Happens When Worlds Collide: Light and Nanomaterials

Naomi Halas, Professor of Electrical and Computer Engineering, Biomedical Engineering, Chemistry, and Physics and Astronomy and Director of the Laboratory for Nanophotonics, *Rice University;* Internal Advisor, *NEWT ERC*

Naomi Halas, a nanotechnology pioneer, recounted how interdisciplinary research using nanoparticles and photonics led to breakthroughs in cancer therapy, solar-powered water desalination, and environmentally friendly hydrogen production. “This is our century,” she declared. “The 20th century was the century of quantum physics, of DNA, enormous discoveries, but the 21st century is the century of ‘Grand Challenges’ that cannot be solved by a single discipline.” It’s the job of engineers to solve them.

Halas’s research on cancer treatment began in the early 2000s in a partnership between Halas and Jennifer West, now Dean of the School of Engineering and Applied Science at the University of Virginia. They found that therapy combining near-infrared lasers and gold nanoshells killed breast cancer cells without destroying the surrounding healthy tissue. (Nanoshells, or hollow nanoparticles made with gold and silica, allow longer light wavelengths than solid nanoparticles. Near-infrared light waves are slightly longer than what is visible.) The nanoshells work with the natural biology of the tumor. When heat is applied by the lasers, the tumors can disappear.

Clinical trials showed the treatment worked against head and neck cancers. But it didn’t work well against prostate cancer, a disease that kills more than 30,000 American men a year. New prostate treatment options were urgently needed; existing therapies, which treated the whole gland, often caused loss of urinary control and sexual function, and could damage adjacent organs.

A key problem in applying nanoparticle and laser therapy was locating the tumor. This required doctors to perform needle biopsies. “Maybe they would get the region of cancer, maybe not,” Halas said. A breakthrough in image processing revolutionized prostate cancer diagnoses and opened the way to making the treatment work. “Fusion imaging,” combining magnetic resonance imaging (MRI) and ultrasound, gave doctors a very high-resolution look at the internal structure of the prostate and allowed them to direct the biopsy needle precisely at the suspected cancerous tumor. With this accurate guide, doctors were able to insert gold-silica nanoshells at the right location.

Applying laser heat precisely was difficult because tissue caused the light to scatter. Researchers found that inserting an optical fiber diffuser provided better control of the laser. The treatment had a 94 percent success rate after a year of clinical trials and has been introduced at nine major hospitals.

Halas and her colleagues also tackled the high cost of desalinating sea water. The standard membrane purification process requires enormous amounts of energy to heat and distill the water. But in 2013, Halas's team found that if you shine sunlight on nanoparticles dispersed in a liquid, the result is instant steam. The team figured out how to turn this discovery into a desalination method, but then looked for ways to scale up the process. Lenses that focused the light increased the distillation rate by more than 50 percent. But the team went further. Applying heat-transfer principles with the help of physicists, they found that the exchange of heat between the already distilled and incoming sea water generated electric vibrations. The whole system became a desalination oscillator, resulting in dramatic increases (500 percent) in the production of fresh water.

That wasn't all. Not only did the team get highly efficient desalination, but the oscillation served to store energy for several hours. "For us, it was sort of a, you know, 'Hey, wow, this is very interesting,'" Halas recalled. But it could be a future direction of her team's research. Halas compared this discovery to Alexander Graham Bell's invention of the telephone, which evolved through multiple innovations into the smartphone—a wireless device with multiple uses beyond its original purpose of wire-carried voice communication. Maybe energy storage is the future of solar desalination, Halas suggested.

The chemical industry uses vast quantities of fossil fuels—both as the feedstock for polymers, but also to produce the heat and high pressure needed to drive chemical reactions. The industry's energy consumption leaves a big carbon footprint and is a significant contributor to climate change. Is there a way to make catalysis happen using nanoparticles and light instead of fossil fuels? Halas and her team knew that metal nanoparticles that react with light can induce chemical changes. But these metals are not good at causing chemical reactions; conventional catalysts are poor at absorbing light.

A solution was found in an antenna-reactor: an antenna made of light-absorbing aluminum "decorated with small catalytic palladium reactor particles" (Swearer, et. al, 2016, p. 8916). This was a way to drive chemical reactions with no external heat source. The device was tried successfully to produce syngas, an important chemical feedstock often made from natural gas. Among those excited about this method were entrepreneurs Trevor Best and Suman Khatiwada, who joined with Halas and colleague Peter Nordlander to found Syzygy Plasmonics. Their first project was creating hydrogen from ammonia. Hydrogen holds great promise as a green substitute for fossil fuel but takes a toll on the environment to manufacture and is expensive to transport. Syzygy claims its reactor, the size of an outbuilding, allows hydrogen to be produced anywhere, making the gas competitive in cost with gasoline and diesel. The underlying photocatalysis technology developed at Rice University can be used to produce other industrial gases and chemicals. The firm won a 2019 U.S. Department of Energy ARPA-E grant and an NSF SBIR Phase I grant.

One area where more research and development is needed in nanoparticles is scaling up production with the necessary precision. "The dark side of innovation," Halas said, is that "anytime you do something different, there'll be people who say, 'No, it doesn't work. No, you're wrong.'" Innovators need to have a tough skin and get used to that. But, she cautioned, "You have to critically think about your own science: 'Is this in fact, what I think it is?' Test many, many times, many different ways to really try to understand the science very, very well."

The Innovation Economy

Kamran Elahian, Co-founder, and Chairman, *Global Innovation Catalyst, LLC;* philanthropist

Kamran Elahian story is one of imagination, audacity, and resilience. Arriving in the United States from Iran at age 18, he earned two bachelor's and a master's degree from the University of Utah, went to work for HP in Silicon Valley, and started his first company at age 26. Altogether, he has created 11 companies. Four became multibillion-dollar enterprises and three failed. He was fired twice. "How many of you have been fired?" he asked the audience. Counting seven raised hands, he said, "Give yourselves a big round of applause for, first of all, having the courage to talk about it. And, second of all, it says that you're a special person, you must have pushed the boundaries one way or another... But if you didn't push the boundaries, if you didn't try to do something that nobody else had ever done, how could you ever know how good you are?"

The period 1979–1981, when Iranian militants held 52 Americans hostage, was not a promising time for an Iranian immigrant—with "my funny accent, my funny name"—to seek venture capital. How Elahian succeeded is a case study in aplomb. Scheduled to speak after lunch at a conference of 800 Florida investors, he watched as the crowd paid scant attention to a series of detail-crammed, 12-minute pitches. Elahian was told that real exchanges would come later during investor meetings with individual companies. All that really mattered was that investors remembered the name of a speaker or the speaker's company. When Elahian's turn came, he listened while the announcer mangled his name. Then, he started silently pacing. Soon the audience was riveted, wondering what he would do next. Assured of their attention, he announced that he wouldn't accept any money from someone who couldn't pronounce his name. "I said, 'Here we go. First name is Kamran. Say it after me." Laughing, the audience complied. Once they had repeated his first and last names several times, he pronounced them all "qualified" to invest in his company. "Sign up to come tomorrow and find out what we are doing," he told the audience. Elahian ended up raising more than he was after, and his "funny name" had become an asset.

Shifting to his main topic, Elahian said the innovation economy is changing everything—industry, government, academia. In the 20th century knowledge economy, ideas were kept secret as they were patented and developed. In the innovation economy, the winners are those ones who can best execute great ideas. Several search engines emerged in the early Internet days—AltaVista, Excite, Bing, Yahoo—but Google mastered how to do it and is now dominant.

Much of the disruption in the innovation economy will come from software and algorithmic tools, which have already transformed the taxi and hospitality businesses. Today's highest-value companies, including Apple, Microsoft, Alphabet, Amazon, Tesla, Nvidia, and Tencent, owe their value to an emphasis on software and algorithmic content.

With so much human knowledge accessible on the Internet, "the job of an educator is not to stand [and] talk to people about theory. It is experiential learning, being a coach. Let your students go and do things themselves." Ask more questions and have the students provide the answers. Multitasking, of the kind his sister—but not he—was expected to learn at home to help take care of siblings, is good preparation for algorithmic thinking.

Stanford was ahead of East Coast universities in bringing business courses into the engineering school. As a result, it spun off "many, many more companies" than other elite schools. Art and design are important, he said. Relying on engineering alone recalls the early days of desktop computing. "To run Windows, you remember, three fingers at once, 'control, alt, delete,' just to get that darn machine started." Introducing interactive design and aesthetics, "you do things differently."

Harbour.Space University, a technology, design, and business school that Elahian founded, with locations in Barcelona and Bangkok, approaches many things differently. In his classes, for instance, students grade each other using an algorithm the school provides. They are much tougher than he would be. Harbour.Space has no full-time faculty members. Instead, it invites instructors from academia and industry to popular destinations, where they teach three hours a day "and the rest of the time play tourist."

Elahian's worst failure, the 1991 Momenta Computer, experienced many problems, but a bad user interface was key. An iPad-type device introduced 18 years before the actual iPad, it was doomed by a 45-second startup delay. Confused customers thought the machines were broken and returned them. "Had we talked to 50 customers, we would have known that, hey, people are saying, 'What is the button? How do you turn this on? How do you get this thing to work?' And we would have said, 'Let's not ship 5,000 of them, let's not bankrupt the company.'" Most startup failures result from not testing the market.

Elahian's eleventh company, Global Innovation Catalyst, has a vision to create 10 million innovation jobs. His pithiest quote: "The best way to predict the future is to create it."

Panel Sessions

Sustaining ERCs Post-Graduation

Deborah Jackson, Program Director, Gen-4 Engineering Research Centers (ERC) and Planning Grants for ERC, *National Science Foundation*

Sarit Bhaduri, Program Director, Gen-4 Engineering Research Centers (ERC) and Planning Grants for ERC, *National Science Foundation*

Rajesh Rao, Director, *Center for Neurotechnology ERC (CNT)*; Professor of Computer Science and Engineering and Electrical and Computer Engineering, *University of Washington*

ERCs approaching the end of their 10-year funding streams must confront a threshold question as they contemplate the future: "Do we really honestly want to

stick together?" Is there a good reason for their multi-institutional, multi-disciplinary team to stay intact? They shouldn't give the answer they think NSF wants to hear. But if the answer is yes, agency staff can provide useful guidance.

Often, the search for continued funding starts by exploring the plethora of NSF funding opportunities beyond the ERC program. These opportunities might allow certain research, educational, and DEI components to continue thriving even if all center work can't continue.

Well before the Center for Neurotechnology (CNT) ERC graduated in 2021, it had built a strong educational arm through relationships with the multi-state MESA (Mathematics, Engineering, Science Achievement) organization and secured grants from NSF's Research Experiences for Undergraduates (REU) and Research Experiences for Teachers (RET) programs. CNT also found an educational and research partner in the venerable DO-IT (Disabilities, Opportunities, Internetworking, and Technology) program begun in 1992 at the University of Washington, CNT's lead institution. From year seven onward, CNT provided incentives for collaborators within each test bed "to make sure that they're on the pathway to be sustained," said panelist and CNT Director Rajesh Rao.

By the end of its second year, the Center for Quantum Networks (CQN) had become "a national magnet for a variety of different activities" and laid a foundation for a future that could extend beyond an ERC's life. It forged collaborations across the University of Arizona—its lead institution—and with NASA. Established to build the technological foundations of a quantum internet, CQN won a 2021 Army research grant to develop mathematical measures of complex multi-site entanglement. Meanwhile, it formed partnerships with more than a dozen companies, which pay for different membership tiers. Those in the highest tier get to work with a CQN researcher of their choice.

A promising funding source for graduating ERCs is NSF's new Technology, Innovation, and Partnerships (TIP) Directorate, which shares many of the ERC program's priorities of convergence, use-inspired and applied research, and industry partnerships, but across all STEM fields. Some ERCs could fit well with NSF's Regional Innovation Engines, aligned with TIP.

Relying on industry partnerships to extend the life of an ERC may mean thinking about new institutional arrangements with fewer university-imposed requirements. These could include forming independent entities or nonprofits to conduct research. ERCs seeking to keep operating can also seek university support for components or ask for a share of a grant's overhead funding.

Four Foundational Components

Gerard Coté, Center Director, *Center for Precise Advanced Technologies and Health Systems for Underserved Populations (PATHS-UP);* Professor of Biomedical Engineering, *Texas A&M University*

Saikat Guha, Center Director, *Center for Quantum Networks (CQN);* Professor of Optical Sciences, *University of Arizona*

Fabio Ribeiro, Center Director, *Center for Innovative and Strategic Transformation of Alkane Resources (CISTAR);* Professor of Chemical Engineering, *Purdue University*

Regan Zane, Center Director, *Center for Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE);* Professor of Electrical and Computer Engineering, *Utah State University*

NSF Program Director Randy Duran, who moderated this panel, encouraged panelists encouraged panelists and attendees to share experiences. He asked each panelist to describe the purpose of their center and to address how it implements one of the core pillars: convergent research, engineering workforce development, diversity and a culture of inclusion, and the innovation ecosystem.

Duran then opened the session to a series of questions and comments from the floor. A member of the audience noted that the all-male panel served as a reminder that all those present need to do a better job when it comes to setting an example of diversity for students. Coté responded that diversity extends beyond race and gender to include, for example, people with hidden disabilities and first-generation college graduates. Nonetheless, panelists stressed that their centers take diversity and inclusion seriously; for instance, by creating a diversity and inclusion board.

Two panelists cited their centers' work with local communities as a way to broaden students' perspectives and build rapport with more stakeholders. PATHS-UP, which develops cost-effective healthcare technologies for underserved communities, engages students in improving nutrition, young people to campus, and conducts outreach. ASPIRE, which develops electrified roadways with coils embedded in the surface to provide continuous charging of electric vehicles, has worked on pilot projects with communities on the west side of Salt Lake City, which has been disproportionately impacted and endured pollution caused by past transportation policies. "Students have real visibility," Zane said. Besides engineering research, ASPIRE students have worked with social scientists on surveys. As a result, they "see firsthand the present case on equity and diversity," he said.

Centers have found that as their work progresses and attracts public interest, they draw in more industry partners and collaborators. In ASPIRE's case, these include the mining firm Rio Tinto, a key supplier of minerals used in electric vehicles that is seeking to reduce its carbon footprint. CISTAR, which works to convert light hydrocarbons into lower carbon-footprint chemicals and transportation fuels, has almost doubled its research funding with industry partnerships. The center and CQN both have connections with national labs. CQN graduate students have gained internships at Sandia National Laboratory and NASA.

Maintaining a steady vision and single culture among center participants from multiple universities can be a challenge, panelists acknowledged. During the pandemic, CQN, which researches the building blocks of long-distance quantum networks to develop an eventual "socially responsible" quantum Internet, formed Zoom-based working groups led by students and post-docs. To prevent silos and disconnected research, it's important to keep insisting that every project fits into an ERC's mission. Asked about resource allocation among the pillars, Coté said his center spends 60% on research and 5% on administration, leaving 35% for other pillars. It's important to link up with other university initiatives to leverage limited funds, he stressed.

Breakout Sessions

Breakout Session by ERC Role

Administrative Directors

FACILITATOR:

Candice Byrd, Director of Finance and Administration, *Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)*; Director of Research Administration, *North Carolina State University*

Participants were directed to the detailed Administrative Directors chapter of the ERC Best Practices Manual on the ERC Association website. Individuals then offered their own recommendations. Eight of these concerned the annual report, including guidelines and a template for internal reporting; a shared spreadsheet with all projects and documents due for the entire center; meeting with senior leadership several months in advance of the peak preparation season; designing efficient systems for files and version management; holding others accountable for content; delegating responsibilities; setting up three phases for report planning, drafting, and final production; setting faculty deadlines a week before material is needed; and hiring a grad student in English to take charge of editing the final document.

For the annual review, suggestions included early planning, giving students a role (including the poster session), simplifying the schedule, holding Industry Day before the site visit, practicing a run-through with all presenters before slides are due to NSF, and staying in touch with the program manager in the lead-up period. Participants' advice on financial management: Build relationships with grant managers at each site, hire an accountant if needed, make PIs organize budgets by project, and stay prepared for a future audit. Other recommendations included making team members feel valued, showing gratitude, and generating standard operating procedures starting on Day One.

Center Directors

FACILITATOR:

Pedro Alvarez, Center Director, *Center for Nanotechnology-Enabled Water Treatment Systems (NEWT);* Professor of Civil and Environmental Engineering, *Rice University*

Of a list of 17 challenges, several are probably common among ERCs, such as resource allocation, building the right leadership team, shared governance, and integrating different disciplinary cultures. Among those heard less frequently were, "contributing value other than widgets," "time to be proactive," and "losing goodwill and trust built up with campuses."

Solutions mentioned included Zoom, which helps people interact from any distance; turn competitors into collaborators; "look at your NSF evaluators as part of your team;" and "have a clear calendar to meet with your team, make sure the important people are available to attend the meetings that are crucial."

The question, "What would you tell NSF to improve the ERC program?" elicited several comments and questions: Reports were found to be useful for certain ERC teams, but less so for others; make the annual reports shorter; get helpful people on the review team who supports the fight; critically looking at the review panel; mitigate the expense of annual reviews; transfer the review to an annual meeting; look deeply into issues presented; set good examples to students; continue to offer to meet monthly with ERCs (especially younger ERC centers); and pull DEI resources.

Diversity Directors

FACILITATOR:

Delia Saenz, Director, Culture of Inclusion, *Center for Bio-mediated and Bio-inspired Geotechnics (CBBG);* Vice Chancellor and Chief Diversity Officer, *University of California–Merced*

This group discussed building a community of practice and the best ways of fostering diversity and a culture of inclusion in each ERC.

Surveys are often key to learning about the diversity of a center or campus. They can provide a lot of valuable data and allow for interactions between demographics, but you need a healthy sample size for the data to be useful. Most universities have a survey research center that will help do surveys and provide consulting for free. It is expensive to do finer detail analysis and complex data interactions.

Survey best practices include having them developed and analyzed by a third party to remove bias and preserve confidentiality—surveys may be anonymous, but people should read and know their center's procedures on harassment in case they see or suspect something. Ethics training is important to know how to deal with sensitive data you might come across in submitted surveys.

Interviews are an alternative to surveys. Caveats include additional costs when a third party is used to avoid bias and required approval from an Institutional Review Board (IRB) when running a K–12 activity involving people under the age of 18.

Small groups discussed two questions: 1) What is the process at individual centers? and 2) How do they try to engage everyone in a culture of inclusion?

Answers to the first question included: using the DEI SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis; incorporating diversity with the industry advisory board to direct their focus; and a need for the director to make a call—because otherwise there can be a power differential in what people are supposed to do versus what they can do. Additional points raised: make sure to listen to students' voices because they can feel very powerless, talk to them about NSF funding so they understand what's going on, and make sure you

understand what they mean when they use certain words; everyone should contribute to SWOT; provide space and convenient times for discussion; and have office hours with the director.

Answers to the second question included: weekly meetings with different groups; picking a topic and advertising in weekly newsletters; having the PI market any culture of inclusion event; engaging and training faculty because they are the ones who have daily interactions with students; and access to NanoHub.

In closing, centers were urged to have mechanisms to hold people accountable, "especially in the area of diversity and culture of inclusion… all the way up to the top," and stay alert to power differentials. "One way to do this is by listening to students" and having mechanisms to do that.

Education Directors

FACILITATOR:

Jean Larson, Education Director, *Center for Bio-mediated and Bio-inspired Geotechnics (CBBG);* Associate Research Professor, School of Sustainable Engineering and the Built Environment and the Division of Educational Leadership and Innovation, *Arizona State University*

In this group, participants were asked to provide one example each of a best practice for engineering workforce development at their centers. Below are selected shared examples:

- All K–12 curriculum that is created as part of ASPIRE will be added to the TeachEngineering.org library of hands-on K–12 engineering curriculum and high school course development.
- One center held a competition where middle and high school students built wearable devices and addressed issues at the intersection of human, animal, and environmental health.
- Involving graduate students in the planning of community projects and outreach, including with farmers, leverages language proficiency and community connections.
- Engineering engagement kits were developed with classroom teachers.
- Graduate students participated in outreach quantum mechanics demos at the Mall of America in Minnesota, providing quantum science ID tags for kids.
- Three post-secondary courses are hosted across the ERC: a synchronous online course, science communication mini-course, and an upcoming course on grant writing.
- Graduate courses at different institutions (synchronously online, with hands-on labs using kits) will be offered as independent study courses at students' home institutions.
- In a "ladder mentoring" effort, new cohorts of teachers and their students engage in multi-year, community-based solar research networks.
- Participating K–12 teachers can borrow kits of bio-tech materials for three weeks, saving their schools money.

Industrial Liaison Officers (ILOs)

FACILITATOR:

Scott Ransom, Industrial Liaison Officer, *Center for Neurotechnology (CNT), University of Washington*

In documenting best practices, the group decided to split them into two categories: one for ILOs and another for the ERCs. Selected responses and insights are captured below.

For ILOs, mentoring is particularly helpful to target attrition and develop small- and medium-sized enterprises. Beyond their mentors, new ILOs feel like the entire group of existing ILOs serves as a best practice in its own right. The fact that this is a close-knit group of ILOs has been positive, as there are always folks to reach out to when there are questions, challenges, etc. Most ILOs came from industry first, so they can seamlessly merge the gap between industry and academia. Skills required for the role cannot be discretely defined and described.

Best practices for ERCs focused largely on recruitment and managing industry. In terms of recruitment, insights included: recruiting for overhead reduction (being able to be part of a "solution" to a real problem has given meaning to sponsored research agreements, making the creation of a value statement for recruiting easy); recruiting for translating/bridging the gap (take on the voice of the customer and translate it in a way that makes sense to them); and recruiting and value proposition (the value proposition needs to connect what your center is doing and what specific gaps in the industry your center is filling). Regarding managing industry, there was discussion about finding the optimal cadence with IAB management and briefing and focusing on the positives when doing NSF site visits, saving challenges for industry conversations.

Student Leadership Council (SLC)

FACILITATORS:

Mehrad Mortazavi, Student Leadership Council, *Center for the Internet of Things for Precision Agriculture (IoT4Ag),* PhD Student, *University of California–Merced*

Ramin Sabbagh, Student Leadership Council, Center for Nanomanufacturing Systems for Mobile Computing and Energy Technologies (NASCENT), PhD Candidate, *University of Texas–Austin*

This session focused on the challenges and best practices of SLCs. Students were asked to write examples of good things at their centers. Several responses included: incentives, such as travel awards and extra funding, to keep students motivated; leadership agreeing to professional development opportunities for Student Leadership Council (SLC) members (including events and a professional development fund); a survey as an incentive to keep ERC leadership involved with students; and a laboratory guide that contains substantial documentation, providing continuity of institutional knowledge, links for networking, and key contacts in all member institutions.

The question arose as to whether there was equal buy-in from every university in an ERC, and the consensus seemed to be "no." One student said the PI's universities were the only ones to engage. "We used to have retreats for the SLC, but other universities didn't show up."

One attendee noted the value of site visits: "I really appreciate when the site visit happens, because those folks who are charged with really pushing us, our culture of inclusion, have been very good about listening to ideas that we have, and then adding them to the next generation." But NSF could do more in helping to build networks that would promote increased collaboration—particularly in diversity—between Predominantly White Institutions (PWIs) and Historically Black Colleges and Universities (HBCUs): "Historically white institutions can learn a great deal from the things that historically Black institutions and Minority-Serving Institutions have been doing for decades." Another attendee said that, too often, when large, well-funded PWIs look for research collaborators, "the [MSIs] are brought in at the last minute to check off the box. And I know nobody endorses that as a value or as a best practice. But it happens more frequently than we would like."

Breakout Session by Topic

ERCs Unite! Collaborative Evaluation and the Multi-ERC Instrument Inventory

FACILITATORS:

Jean Larson, Education Director, *Center for Bio-mediated and Bio-inspired Geotechnics (CBBG);* Associate Research Professor, School of Sustainable Engineering and the Built Environment and the Division of Educational Leadership and Innovation, *Arizona State University*

Adam Carberry, ASU Education Lead, *Center for Nanotechnology-Enabled Water Treatment Systems (NEWT);* Associate Professor, The Polytechnic School, *Arizona State University*

MEETING SESSIONS

Megan O'Donnell, Evaluator, *CBBG and Center for Quantum Energy and Sustainable Solar Technologies (QESST)*

Gillian Roehrig, Education Director, *Center for Advanced Technologies for Preservation of Biological Systems (ATP-Bio);* Professor of Science Education, Associate Director of STEM Education Center, *University of Minnesota*

Michelle Jordan, Education Director, *QESST;* Associate Professor, Biosocial Complexity Initiative, *Arizona State University*

This session served as an informational meeting and workshop to help develop the Multi-ERC Instrument Inventory (MERCII). The inventory grows out of a project by the Tri-ERC Evaluation Consortium (TEEC) to develop a comprehensive set of tools to evaluate the strength of ERCs in education and promoting diversity. One of the purposes of the project is to provide convenient instruments that educators can use to create their own surveys. TEEC comprises representatives of six ERCs led by Arizona State University, which obtained an NSF grant for the project in 2020.

In the session, PI Carberry and members of his team explained MERCII and the purpose of the session, and then guided participants to log onto the MERCII website and fill out a test survey.

The survey asked respondents to identify their ERC, their role in it, and how many years they have been involved. The survey then incorporated the name of the ERC into subsequent questions, so the answers would be specific to a particular ERC. For instance, an early set of questions asked how well the respondent understood the ERC's mission, the concepts associated with its fields of study, how its research helps people address real-world issues, which problems the ERC addresses, and potential career pathways associated the ERC's field of study. Other questions probed how well the ERC did at improving the respondent's professional skills (for instance, taking on leadership roles, conducting research in a team), and the ways it improved research skills. Further on, the survey delves into whether an individual has been treated fairly and made to feel that their lived experiences are valued by other center members.

Industry University Cooperative Research Centers (IUCRC) Program

FACILITATORS:

Behrooz Shirazi, IUCRC Program Officer, Directorate for Engineering, *National Science Foundation*

Scott Ransom, Industrial Liaison Officer, *Center for Neurotechnology (CNT), University of Washington*

This session provided an overview of the Industry University Cooperative Research Centers (IUCRC) Program, which received its first center proposal in 1972. This program serves as a catalyst to bring together collaborators from government, university, and industry and fosters an environment conducive to seamless collaboration. IUCRC outcomes include driving innovation, high impact research, and skilled workforce development. Multiple NSF Directorates support IUCRCs, including Engineering (ENG); Mathematical and Physical Sciences (MPS); Computer and Information Science and Engineering (CISE); Social, Behavioral, and Economic Sciences (SBE); and Geosciences (GEO). There are

currently 84 active centers across 120+ US universities, 700 member organizations, 380+ large firms, 220+ small firms (500 or fewer employees), and 20+ federal/state government entities.

Two examples of successful IUCRCs are the Center for Hardware and Embedded System Security (CHEST), which addresses the research challenges that industry faces in the design, protection, and resilience of hardware from the security vulnerabilities associated with electronic hardware, and the Center for Space, High-Performance, and Resilient Computing (SHREC) that assists industry, government, and research organizations' mission-critical computing endeavors.

The path to IUCRC creation involves several stages, including ideation, submission of a planning grant proposal, NSF bootcamp training, and submission of a center proposal.

Critical elements to IUCRC success are center-wide collaboration, strong industry engagements, strong administrative technical leadership, and a strategic vision or roadmap. There are multiple resources available to help build and launch a successful IUCRC, including NSF Program Directors and Evaluators, the VentureWell team, and the IUCRC website (www.iucrc.nsf.gov). Interested individuals should refer to IUCRC Solicitation NSF 20-570 for details on eligibility and restrictions.

Financial Structure and Management of an ERC

FACILITATORS:

Candice Byrd, Director of Finance and Administration, *Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST),* Director of Research Administration, *North Carolina State University*

Tsai-Tsai O-Lee, Administrative Director, *Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS)*

This session began with a short activity where attendees at each table introduced themselves with the following information: name, role, ERC, campus, years with the ERC, and one thing they would like to get out of this session. They were asked to draw one card from a small pile at the center of the table and answer questions—referred to as "table topics," which were fun and personal.

Then the session moved into a presentation that discussed ERC reporting requirements and other major considerations for those responsible for the financial structure and management of ERCs.

The funding categories for an ERC are restricted, unrestricted, and associated. In terms of ERC funding allocation, there is no manual and no prescribed method for funding allocation, with the center leadership responsible for deciding what is acceptable (different advisory boards and directors will have different ideas). To maintain equity and transparency during funding allocation and when setting funding priorities, it is a best practice to have a written, established process. Minimize conflicts of interest and consider the use of a review board.

There are specific reporting requirements that should be considered. ERCs must submit technical narrative reports and financial reports. Best practices for reports include providing clear reporting guidelines with templates and due dates; using Excel templates for reporting when possible; requesting sub-award invoices to include the same level of information when possible; and planning and setting due dates at each level of reporting so that you have time for corrections. Financials should be managed with the expectation that the ERC will encounter at least one audit in its lifetime.

The Art & Science of Building Community

FACILITATOR:

Delia Saenz, Director, Culture of Inclusion, *Center for Bio-mediated and Bio-inspired Geotechnics (CBBG)*; Vice Chancellor and Chief Diversity Officer, *University of California–Merced*

This session began with table introductions and a discussion on inclusion, which can be challenging depending on personality type. If someone is a stranger, it is difficult to know how to interact with them most effectively. Diversity and inclusion in any endeavor are key.

Groups work better when they are inclusive. What is a group? From a psychological perspective, groups are two or more individuals who share a common goal. There is stability in a group relationship and regular contact amongst its members. Group members also have a level of interdependence, as group outcomes impact each other. Successful groups have a sense of belonging. Why do we join groups? To develop a sense of identity, fulfill desires for association/affiliation, and to achieve bigger goals than one could individually.

There is often an expectation that we conform to group activities. Tensions naturally exist between group needs and individual desires. Participants shared the following examples:

- Departments where there is a culture of not admitting mistakes due to the need to feel perfect—the pressure is bad on those with imposter syndrome, which can be detrimental to the group.
- Faculty meetings with a power dynamic where junior faculty are scared to voice opinions because they do not want to go against those in senior positions.

Some people will take credit and speak loudly to make a point, while others wait patiently, which creates imbalance. We need to bring these voices together, but how? How do we deal with these situations? What if it is a full professor always interrupting a student or an assistant professor? Who will have the courage to stop them?

These often unintentional slights are called microaggressions and the person that notices the microaggression is responsible for direct approach. It is important to discuss norms and provide training on what microaggressions are. Before addressing the microaggression, determine whether a power differential exists first. Is it safe to address the issue? Has anyone else noticed the behavior?

When addressing, try using the language, "I noticed that you said this..." and "I think it would be better if..." When dealing with microaggressions, creation of safe spaces is important. It's wise to have a central person that is not part of a power dynamic at play.

We all enter space with personal experience/background in the broader societal context of stereotypes/biases. Consider how the implicit bias colors interactions.

Having a clear mission statement for your ERC can incorporate excellence on the technical side and excellence in process and outcome for its members. What does your center do (not just technologically or scientifically)? Who is your center as a gathering of people/team?

Do people at all levels have the same opportunity for excellence, whether a transfer at undergrad level or new PhD student? Are all demographic groups considered equally?

Ensure that everyone gets to contribute to and be recognized for their role in achieving your vision/success of the ERC. Everyone should have the opportunity to reap the ERC's benefits. Aspire to cultivate the well-being of your members and achieve excellence in learning, discovery, and service by intentionally honoring and welcoming diverse contributions and perspectives.

Using Mentoring Contracts in ERCs

FACILITATORS:

Jennifer Chandler, Director for Diversity and Leadership, *Center for Bio-mediated and Bio-inspired Geotechnics (CBBG)*; Associate Teaching Professor, MY, CISA - Leadership and Integrative Studies, *Arizona State University*

Ky'la Sims, Student Leadership Council, *Center for Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE), Purdue University*

This session focused on effective mentoring practices: be prepared, be transparent, listen, provide positive feedback, recognize problems, lead by example, and be open-minded.

Attendees talked with people at their tables about mentoring experiences and best practices for mentoring. The session then moved into role-playing activity of building a mentoring contract, where each person took on the role of a mentor and mentee as they completed a sample mentoring contract.

Tables discussed what clauses or requirements would go into the contract. These included that mentors will go to at least one conference per year with their mentees and both parties will be on time for meetings. Contracts should also include things like expectations for graduation, publications, and coursework.

One concern that attendees expressed was that this process would be awkward to be brought up as a mentee and would likely not be initiated by a "bad" mentor. So, mentoring contracts may only be feasible and/or useful if they are required by departments.

Perfect Pitch Competition

The Perfect Pitch Competition tests the expertise, presentation skills, and poise under pressure of current undergraduate students, master's students, PhD students, and post-docs participating in ERC research. In a Shark-Tank-style format, contestants give a jargon-free, 90-second elevator speech they'd use to win over sponsors, describing how their research solved a real-life problem in a unique way, benefited society, and helped fulfill their center's mission.

In introductory remarks, NSF Program Director Deborah Jackson asked attendees to imagine a scenario in which they find themselves in an elevator with Susan Margulies. "You've got to say something to her that makes her want to continue engaging you and learn more about your vision for a new research concept or a novel research approach," Jackson said. "If you've got some really important, exciting research results, you've got that little moment in time where you have Susan as a captive audience and you're going to try to get her to engage you once those elevator doors open."

The 14 contestants had each won a Perfect Pitch competition at their ERC. The top prize for this competition was $5,000; second prize, $2,000; and third prize, $1,000. The first-place winner's ERC receives the Lynn Preston Trophy, named for the program's founding director, and keeps it until the next Perfect Pitch winner is announced.

Lauren Mazurowski from Yale University and the Center for Nanotechnology-Enabled Water Treatment (NEWT) won first place for her presentation titled, "ReCuver Copper." Winning second place was Eleanor Fadely from University of California–Davis and the Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) for her presentation titled, "Manganese Biomineralization for Heavy Metal Remediation." The third-place winner was Marium Rasheed from Utah State University and the Center for Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE) for her presentation titled, "Composite Hybrid Energy Storage System (CHESS)." The full list of contestants is in Appendix B: Perfect Pitch Competition Projects.

The judges of this year's competition were Jim Chung, Associate Vice President for Research Innovation and Entrepreneurship at George Washington University; Deborah Goodings, Professor and Associate Dean, College of Engineering and Computing at George Mason University; Andre Marshall, Vice President for Research, Innovation, and Economic Impact at George Mason University, and Steve McKnight, Vice President for Strategic Research Alliances at Virginia Tech. McKnight was unable to attend the live competition.

Graduation and Perfect Pitch Awards Ceremony

The 2022 NSF ERC Biennial Meeting culminated with a reception that featured concluding remarks by Susan Margulies, a video greeting by NSF Director Sethuraman Panchanathan, announcement of the Perfect Pitch Competition winners, and a graduation ceremony for the seven centers completing their decade with the program: 1) Center for Quantum Energy and Sustainable Solar Technologies (QESST); 2) Center for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT); 3) Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST); 4) Center for Re-Inventing the Nation's Urban Water Infrastructure (ReNUWIt); 5) Center for Neurotechnology (CNT); 6) Center for Ultra-wide Area Resilient Electric Energy Transmission Networks (CURENT); and 7) Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS). Encouraged over the years to raise public awareness of their work, the graduating centers provided videos touting their successes and, in some cases, hinting at continued operation.

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APPENDIX A: MEETING AGENDA

TUESDAY, SEPTEMBER 20	
8:15 AM – 8:30 AM	**WELCOME AND INTRODUCTION** **José Zayas-Castro,** Division Director, Division of Engineering Education and Centers, National Science Foundation
8:15 AM – 8:30 AM	**OPENING REMARKS** **Susan Margulies,** Assistant Director, Directorate for Engineering, National Science Foundation
8:30 AM – 9:30 AM	**KEYNOTE 1** **Curtis R. Carlson,** Distinguished Executive in Residence, Worcester Polytechnic Institute; Professor of Practice, Northeastern University; President and CEO, SRI International, 1998–2014
9:30 AM – 10:00 AM	**NEW ERC INTRODUCTIONS**
10:45 AM – 11:45 AM	**PANEL: ERC POST-GRADUATION SUSTAINABILITY** **Deborah Jackson,** NSF ENG/EEC Program Director **Sarit Bhaduri,** NSF ENG/EEC Program Director **Rajesh Rao,** Center Director, CNT
1:15 PM – 2:15 PM	**KEYNOTE 2** **Calvin Mackie,** President and CEO, STEM NOLA
2:45 PM – 3:45 PM	**BREAKOUT SESSION 1** **Administrative Directors** **Center Directors** **Diversity Directors** **Education Directors** **Industrial Liaison Officers** **Student Leadership Council**
3:45 PM – 4:45 PM	**PRESENTATION OF BREAKOUT SUMMARIES**
4:45 PM – 5:00 PM	**WRAP-UP** **José Zayas-Castro,** Division Director, Division of Engineering Education and Centers, National Science Foundation
5:00 PM – 7:00 PM	**NETWORKING RECEPTION AND POSTER SESSION**

APPENDIX A: MEETING AGENDA

WEDNESDAY, SEPTEMBER 21	
8:00 AM – 8:15 AM	**WELCOME AND OPENING REMARKS** **Nadia A. El-Masry,** Deputy Division Director (Acting), Division of Engineering Education and Centers, National Science Foundation
8:15 AM – 9:15 AM	**KEYNOTE 3** **Naomi Halas,** Stanley C. Moore Professor of Electrical and Computer Engineering, Rice University
9:15 AM – 10:15 AM	**PANEL: FOUR FOUNDATIONAL COMPONENTS** **Gerry Cote,** Center Director, PATHS-UP **Saikat Guha,** Center Director, CQN **Fabio Ribeiro,** Center Director, CISTAR **Regan Zane,** Center Director, ASPIRE
10:30 AM - 12:00 PM	**PERFECT PITCH COMPETITION**
1:00 PM – 2:00 PM	**KEYNOTE 4** **Kamran Elahian,** High-Tech Entrepreneur with Four Unicorn IPOs
2:00 PM – 3:30 PM	**BREAKOUT SESSION 2** **ERCs Unite! Collaborative Evaluation and the Multi-ERC Instrument Inventory** **IUCRC Overview** **Financial Structure and Management of an ERC** **The Art and Science of Building Community** **Using Mentoring Contracts in ERCs**
4:00 PM – 4:15 PM	**WRAP-UP AND CLOSING REMARKS** **Don Millard,** Deputy Assistant Director, Directorate for Engineering, National Science Foundation
4:15 PM – 4:30 PM	**ACKNOWLEDGEMENTS**
5:30 PM – 8:00 PM	**GRADUATION CEREMONY, PERFECT PITCH AWARDS, AND POSTER SESSION** **Susan Margulies,** Assistant Director, Directorate for Engineering, National Science Foundation **Sethuraman Panchanathan,** Director, National Science Foundation

APPENDIX B: PERFECT PITCH COMPETITION PROJECTS

1. **FIRST PLACE WINNER:** Lauren Mazurowski, Yale University, Center for Nanotechnology-Enabled Water Treatment (NEWT): *ReCuver Copper*

2. **SECOND PLACE WINNER:** Eleanor Fadely, University of California–Davis, Center for Bio-mediated and Bio-inspired Geotechnics (CBBG): *Manganese Biomineralization for Heavy Metal Remediation*

3. **THIRD PLACE WINNER:** Marium Rasheed, Utah State University Center for Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE): *Composite Hybrid Energy Storage System (CHESS)*

4. Courtnie Jean Paschall, University of Washington, Center for Neurotechnology (CNT): *Virtual Reality for Brain-Computer Interface*

5. Narayanan Rengaswamy, University of Arizona, Center for Quantum Networks (CQN): *Enabling Quantum Advantages by Mitigating Errors*

6. Katherine Jiang, Stanford University, Center for Power Optimization of Electro-Thermal Systems (POETS): *Waste Heat Recovery in Power Plants Through Fluidized Water Harvesting System*

7. Gokulanand Iyer, University of Pennsylvania, Internet of Things for Precision Agriculture ERC (IoT4Ag): *Biodegradable, Cellulose-Based Soil Sensors for Precision Agriculture*

8. Grant Marsden, Northwestern University, Center for Innovative and Strategic Transformation of AlkAne Resources (CISTAR): *Creating Compact Fuel Conversion Through Microkinetic Modelling*

9. Delta Ghoshal, Georgia Tech, Center for Cell Manufacturing Technologies (CMaT): *Patient-Specific Multiple Myeloma on a Chip*

10. Hayley Richardson, North Carolina State University, ASSIST Center: *Non-Invasive Continuous Stress Monitoring*

11. Joseph Sushil Rao, University of Minnesota, Center for Advanced Technologies for the Preservation of Biological Systems (ATP-Bio): *Shelf-Stable Organs: Ending the Transplant Waitlist*

12. Amruta Pai, Rice University, Precise Advanced Technologies and Health Systems for Underserved Populations (PATHS-UP): *Digital Health Coaching for Diabetes Management in Underserved Populations*

13. Jesse Rivera, University of California–Los Angeles, Translational Applications of Nanoscale Multiferroic Systems (TANMS): *Healing Broken Hearts Through Multiferroic Antennas*

14. Josh Javor, Boston University, Center in Cellular Metamaterials (CELL-MET): *Contactless EKG*

APPENDIX C: MEETING EVALUATION RESULTS

In consultation with the American Society for Engineering Education (ASEE), Quality Evaluation Designs (QED) designed a post-meeting evaluation survey, which was administered on the last day of the event. The purpose of the survey was to understand if the meeting objectives were achieved, as well as to obtain general feedback on overall satisfaction with the event and make recommendations for future meetings. QED added demographic items and additional questions to explore customer segments. The survey achieved a 68% response rate from the 190 attendees. The following report summarizes evaluation results. All data were collected in accordance with Ethical and Independent IRB ID #22196.

SUMMARY OF FINDINGS

PARTICIPANT DEMOGRAPHICS

In the survey, attendees were asked to provide demographic information about their gender, race/ethnicity, academic status, and ERC generation, and role. In terms of gender, slightly more than half of attendees (53%) self-reported as female. Approximately 16% of attendees self-reported as members of underrepresented ethnic/racial groups *(see Figure 1: Race/Ethnicity of Respondents).*

In terms of ERC generation, there was almost equal representation between Gen-3 ERCs (48%) and Gen-4 ERCs (46%). A variety of ERC roles were represented at the meeting, with the most representation from graduate students/post-docs (20%), Diversity/Education Directors and staff (19%), and Center Directors/Co-PIs/Deputy Directors (16%) *(see Figure 2: ERC Role of Respondents).*

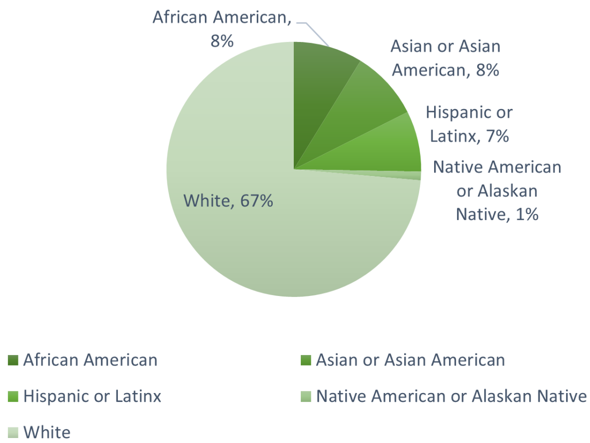

Figure 1: Race/Ethnicity of Respondents

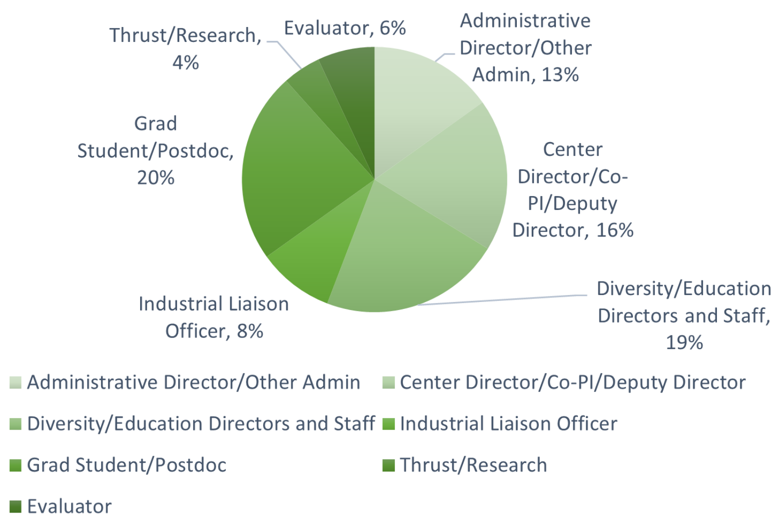

Figure 2: ERC Role of Respondents

Meeting Objectives

The objectives of the 2022 NSF ERC Biennial Meeting were to: 1) provide attendees with opportunities to network and collaborate with each other to share best practices and develop ongoing communities of practice across ERCs; and 2) provide attendees with opportunities to talk with NSF Program Officers in a less formal venue than site visits.

When asked to rate their networking experiences, 80% of attendees rated the frequency of their interactions as good-excellent, and 88% of attendees rated the value of their networking interactions as good-excellent, indicating that an overwhelming majority felt that the meeting provided them with frequent and high-quality networking opportunities. One respondent commented that, "It was a large event with quite a bit of participants, but it felt intimate. I really enjoyed seeing my ERC colleagues after 3 years." Another commented, "I enjoyed the opportunity to network and collaborate across the centers during the meeting but am really excited to keep it going by pursuing several new ideas with ongoing and new connections."

	Rating*
Interactions with members of my own ERC	3.4
Interactions with members of other ERCs who share my ERC role	3.4
Interactions with NSF Program Directors	3.2
Interactions with NSF Program Directors	3.1

Figure 3: Frequency of networking opportunities with other attendees

*(1= Poor, 2= Okay, 3= Good, 4= Excellent)
Note: Interactions with industry professionals was 2.8, but there were few industry professionals at the conference.

Attendees were asked to rate their networking interactions by ERC role (see Figure 3: Frequency of networking opportunities with other attendees). On average, participants found their networking interactions to be good-very good, with ratings ranging from 3.1/4.0 for Interactions with members of other ERCs serving in roles other than mine to 3.4/4.0 for Interactions with members of my own ERC & Interactions with members of other ERCs who share my ERC role. Interactions with NSF Program Directors were rated 3.2/4.0. Throughout open-ended survey responses, attendees stressed the value of interacting with members from other ERCs who shared their same role and asked for more emphasis to be placed on this in the future. Representative comments included:

- "I said it in 2019 too— Evaluators NEED a breakout when you have the other role-specific breakout sessions. We were trying to organize something and host [our own] meeting but should not have to resort to that."

- "I was very disappointed... that we didn't get more time with our peer group across ERCs. In past years there has been more than one hour to meet as a group. We need time to develop those relationships and discuss best practices."

Many also commented that networking would have been better facilitated if name badges conveyed more information—for example, "Center Names and Roles, rather than universities," "ERC and year/generation," and "add ribbons... indicating looking for mentor/mentee." Participants were asked the number of new connections they made that they expect to continue after the meeting. All but five attendees made at least one connection. Sixty-nine percent reported making between one to four connections, while 28% reported making five or more.

Meeting Value

The Biennial Meeting received an average Overall Value rating of 7.4/10 or moderately valuable from attendees. In response to the question, *"To what extent will your having attended the conference support or improve your effort or outcomes at your ERC?"* 40% of survey respondents reported that attending the meeting will support or improve their ERC moderately, while 39% reported to a great extent.

Session Value

In terms of session value, the standouts were Calvin Mackie's keynote presentation and the Perfect Pitch Competition. In their responses to short answer components of the survey, attendees expressed the desire to have longer breakout and discussion times in lieu of long keynote presentations, with comments including:

- "Need to have more time to interact with our peers at other Centers..."

- "I think having less speakers and more break-out sessions to allow ERCs to interact with each other could have been more valuable."

In addition, many students and trainees did not find value from the sessions because they felt the topics were not directly relevant to their roles and activities.

Logistics

Attendees were asked to rate their satisfaction with various aspects of meeting logistics and organization. On average, ratings ranged from satisfied to very satisfied, except for the food, for which the average rating was unsatisfied.

ERC Teams' Significant Challenges

Participants were asked to list the top two challenges they face in their ERCs. The prompt generated 143 responses. The top five most cited challenges were: 1) administrative and reporting burden (25 responses); 2) transition to graduation/sustainability (16 responses); 3) DEI (15 responses); 4) ERC teambuilding (15 responses); and 5) trainee disengagement (11 responses).

Many participants commented on the excessive burden in meeting NSF reporting requirements. This comment was often linked to staffing and burnout. Several comments focused on concerns about sustainability after graduation. Issues related to DEI were also among the top challenges. In some cases, comments focused on frustration with existing dynamics related to race and ethnicity. Other comments focused on lack of support for identifying and implementing strategies to enhance DEI. Although four student trainees cited lack of support as a challenge, ERC leaders listed trainee disengagement as a concern three times more often.

Interpretations and Recommendations

The top recommendations from the 2019 ERC Biennial Meeting, as indicated by attendees in the 2019 post-conference evaluation survey, were to 1) provide breakout opportunities for all attendees (including evaluators and students); 2) create a breakout session for attendees with different ERC roles for a discussion that allows for different perspectives to be shared; 3) create time near the beginning of the meeting for introductions and to clearly state meeting objectives; and 4) rethink how to involve NSF Program Officers in the meeting program.

The recommendation for breakout opportunities for all attendees was reiterated by 2022 meeting attendees in responses to the post-meeting evaluation survey. As such, the evaluation team recommends addressing this recommendation more effectively in future meetings. In 2019, respondents requested breakout sessions across ERC roles. While this would be potentially valuable, the evaluation team believes that time would be better spent enabling people with the same roles to spend more time together.

As recommended in the 2019 evaluation, the 2022 meeting did state meeting objectives in the introduction and site leaders briefly introduced their teams. The 2022 meeting program was altered to facilitate more interaction between participants and NSF Program Officers. Survey results relating to the frequency of interaction with Program Officers were similar across the two years, with approximately 66% reporting valuable interactions. Although frequency of interactions was rated high generally, participants overall requested more interaction with Program Officers. The conference team will take this into consideration for future meetings.

Overall, the 2022 ERC Biennial Meeting was successful in meeting the objectives. The evaluation team offers the following actionable recommendations for future meetings:

1. Increase the number and duration of breakout sessions so attendees can have higher quantity and quality of time to interact with others in similar roles.

2. Add a breakout session for trainees/students and evaluators.

3. Reduce the number of presentations/lectures and increase the amount of time for questions and discussion with NSF Program Officers.

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