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The National Academy of Sciences was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The National Academy of Engineering was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The National Academy of Medicine (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the National Academies of Sciences, Engineering, and Medicine to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

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Diversifying any organization requires leadership’s commitment to progress and sustainability. The value diversity brings to the creativity of engineering and to leadership in general has been well articulated (Castillo-Page and Anderson 2022; May 2022; Slaughter 2020). Diversity is particularly important to the National Academy of Engineering (NAE) because its charter makes it an advisor to the federal government. Unfortunately, the engineering profession and the NAE have been slow to achieve significant diversity.

Historically, racial minorities and women were not recruited into engineering majors at universities, and they were sometimes even dissuaded from applying (Pierre 2015). In 1974 only 12 African Americans received a PhD in engineering in the United States out of a total of about 3,000 degrees granted. In 1973, under the leadership of the then president of the NAE, Robert Seamans, the NAE launched a program to correct this deficiency called the National Advisory Committee of Minorities in Engineering (NACME). This initiative was in response to a recommendation presented by Percy Pierre to the 1973 NAE Symposium on Minorities in Engineering. NACME was led by industrial CEOs and worked with the Alfred P. Sloan Foundation to create programs that would increase the number of minority graduates in engineering. In 2021, 611 PhD degrees were awarded to underrepresented minorities (URMs), representing 5% of the nation’s total. Many of the current NAE members who are URMs participated in programs created by Sloan with the help of NACME industrial members.

In 1975, eleven years after its founding, the NAE elected its first member from a URM group. Among the first 1500 members elected to the NAE, only 3 were URMs. Between 2004 and 2013, only 3% of elected members were URMs. The NAE began to take proactive action in 2014 by providing incentives for election based on nominations of URMs (and women), and during the next decade the election of URMs was 9% of the total. Nominations increased, and the search committees looked with more intensity at potential candidates from minority groups—and the effort paid off.

In response to the murder of George Floyd in 2020, John Anderson wrote a letter to NAE members acknowledging that the NAE should use this opportunity to do more to promote diversity in the engineering profession and the NAE. Warren “Pete” Miller replied to that letter, suggesting ways that the NAE might respond. Percy Pierre suggested establishing an advisory committee to work with the NAE president in this endeavor. The Racial Justice and Equity Committee (RJ&E) was formed, and Percy Pierre was the founding chair of the committee. Two of the charges to the committee were to bring awareness to NAE members of the importance of racial and ethnic diversity to the engineering profession and to increase the number of URMs elected to the NAE and those serving in leadership positions.

In March 2020 there were 49 self-reported URM members of the NAE; in February 2023 there were 123,
representing 5% of the NAE’s membership. This significant increase in just three years resulted from the work of many individuals who understand the importance of a diverse membership of outstanding engineers. Of note is the tremendous effort by NAE member Darryll Pines, chair of the RJ&E Subcommittee on Membership, to augment the work of the NAE to find highly qualified persons to nominate for NAE membership. While more progress is still needed, we should reflect on a positive outcome that resulted from the commitment and resolve of so many NAE members.

The RJ&E Committee also established a standing member-led committee titled URMNAE, which invites all NAE members to discuss barriers minority groups face in the engineering profession and in election to the NAE and to plan activities that promote inclusion of minority populations. This committee is led by Warren Miller and Rafael Bras. A social media program is under development by RJ&E Committee Co-Chair Wanda Sigur to promote engineering among young people from underrepresented groups in our society.

In the long term, developing a more diverse membership of the NAE essentially depends on drawing more young people into the study of engineering from all segments of our society. By 2060 the US population is projected to be only 22% non-Hispanic white males. The engineering profession cannot flourish by relying on this narrow segment of our population. The future strength of the United States’ economy, health, and security depends on maintaining its leadership position in engineering. Continual renewal of an excellent workforce is necessary, which will require the inclusion of all segments of our society. The NAE can serve the nation by leading the way, and we shall do so.

References


The NAE dedicates the winter issue of *The Bridge* to papers from The Grainger Foundation Frontiers of Engineering Symposium (also known as US Frontiers of Engineering [US FOE]), held in September each year. I am delighted to be the guest editor of this issue, which includes a selection of papers from the 2023 US FOE meeting that I chaired. The meeting was hosted by the University of Colorado Boulder College of Engineering and Applied Science.

I would like to remind our readers that the names of the Frontiers of Engineering program and the US-based event were changed last year in recognition of the extraordinary endowment gift of $10M from The Grainger Foundation that the NAE received. We still use “US FOE” when referring to the annual meeting for US engineers if the shorter term works better in a particular context.

The Grainger Foundation Frontiers of Engineering symposia bring together a diverse group of highly accomplished, early-career engineers who represent the best and brightest from academia, industry, government, and nonprofit sectors across all engineering disciplines. In addition to the US FOE, the series includes bilateral programs with Germany, Japan, China, and the European Union. The events provide an opportunity for competitively selected participants to learn about cutting-edge and impactful developments and to network and engage in intellectual discussions crossing traditional boundaries in engineering.

The technical sessions at the 2023 US FOE covered the following topics:

- Resilience and Security in the Information Ecosystem, cochaired by Cody Buntain (University of Maryland) and Ewa Syta (Trinity College). Talks provided perspectives on a decade of research on online rumoring, misinformation, and disinformation; design vulnerabilities in a post-Twitter age; the dismantling of trust and safety efforts in social media; and opportunities and challenges for bridging engineering, research, and policy.

- Engineered Quantum Systems, organized by Joshua Combes (University of Colorado Boulder) and Sara Gamble (US Army Research Office), with presentations on the fundamental challenges of scaling quantum systems, bridging the knowledge gap in engineered quantum systems from basic research to applications, and engineering software for the quantum computers of today and the future.

- Complex Systems in the Context of Health Care, cochaired by Mariel Lavieri (University of Michigan) and Parika Petaipimol (Upstream Bio). Speakers covered engineering human organoids and organs-on-chips, improving blood collection operations at the American Red Cross, complex global supply chains in the life science industry, and utilizing limited public health resources to control infectious diseases.

- Mining and Mineral Resource Production, organized by Fiorella Giana (Freeport McMoRan) and Aaron Noble (Virginia Tech), which included presenta-
tions on our historical dependence on minerals and new mineral demands, mining and sustainability, and modern mining of a domestic lithium-boron deposit.

The meeting also included a breakout session that facilitated small group discussion about attendees’ research and technical work as well as tours of the Joint Institute for Laboratory Physics, several engineering laboratories, and the building that houses the Ann and H.J. Smead Department of Aerospace Engineering Sciences. The dinner speaker was Dr. Diane McKnight (NAE; University of Colorado Boulder), who spoke about the environmental impacts of mining in the Colorado Rocky Mountains. The symposium program, abstracts of the presentations, and (where permission was granted) links to the slides of the presentations are all available at the US FOE website (naefrontiers.org).

We thank the sponsors of the 2023 US FOE meeting: The Grainger Foundation, the University of Colorado Boulder College of Engineering and Applied Science, the National Science Foundation, the Air Force Office of Scientific Research, the DOD OUSD(R&E)-Laboratories and Personnel Office, Cummins Inc., and individual donors.

The 2023 meeting concluded my service as chair of the US FOE program. The next US Frontiers of Engineering Symposium will be held on September 11–14, 2024, at the National Academies’ Beckman Center in Irvine, California. We encourage you to nominate outstanding early-career engineers in February each year to participate in this program. This will allow us to continue to facilitate cross-disciplinary exchange and promote the transfer of new techniques and approaches across fields in order to sustain and build US innovative capacity.
Over the past decade, mis- and disinformation have become increasingly prevalent within social media platforms and across the broader information ecosystem.

From Accidental Rumors to Pervasive Disinformation
A Decade of Misinformation Research

Kate Starbird is associate professor, Department of Human Centered Design & Engineering (HCDE), and director, Center for an Informed Public, the University of Washington.

At the University of Washington, my colleagues and I have been studying online rumoring for more than a decade. Rumors are unofficial stories spreading through informal channels. There’s a long history of social science research on rumors and online rumoring (e.g., Allport and Postman 1945; Kapferer 2017; Shibutani 1966). That work describes rumors as a natural byproduct of the collective sensemaking process that occurs during times of crisis as people attempt to cope with uncertain information under anxiety. Rumors, in that view, serve informational, emotional, and social purposes. Importantly, while many rumors are false, some turn out to be true.

The concept of rumors is valuable for understanding how false or uncertain information spreads online, but other terms can be useful for highlighting aspects of veracity and intent. Misinformation is information that is false, but not necessarily intentionally so. Disinformation is false or misleading information that is purposefully seeded and/or spread for a specific objective (e.g., financial, political, or reputational). Over the past decade, mis- and disinformation have grown and metastasized within social media platforms and across the broader information ecosystem.
The Boston Marathon Bombings: Clickbait Rumors, Sensemaking Rumors, and Conspiracy Theories

Together with events from Hurricane Sandy a few months prior, the Boston Marathon bombings of 2013 marked a tragic inflection point in the evolution of how people used social media during crisis events and a point of recognition of how collective sensemaking could go awry in online environments.

Using application programming interfaces (APIs) that were publicly available at that time, my team collected and analyzed about 10 million tweets related to the bombings (Maddock et al. 2015; Starbird et al. 2014). We employed a combination of network graphing, temporal visualizations, and manual analysis of tweet content to identify several rumors spreading in that conversation. We also identified three salient types of online rumors: clickbait rumors, sensemaking rumors, and conspiracy theories.

Clickbait rumors are cases where people purposefully spread sensational (and false) claims. In 2013, bad actors were beginning to recognize that they could leverage events to gain visibility through sensational claims, often accompanied by images. The attention they captured could lead to instant cash or lasting reputational gains.

In online sensemaking rumors, seemingly well-meaning people attempt to make sense of a dynamic and anxiety-producing event. After the bombings, there was considerable activity around trying to identify the culprits, and in several cases, the crowd got it wrong—falsely accusing innocent people. Often, the mistakes were accidental.

But in some cases, the sensemaking process was purposefully manipulated. After the event, there was a moment of collective reflection as people recognized that digital volunteerism could quickly shift to digital vigilantism (Madrigal 2013).

A conspiracy theory is an explanation of an event or situation that suggests it resulted from a secret plot or conspiracy orchestrated by sinister forces. Online conspiracy theories are a corrupted form of sensemaking, where the theory—that the event was orchestrated by secret forces—is predetermined, and the audience works to assemble evidence to fit that theory. New conspiracy theories often rely upon a set of tropes or common story elements from past ones. In the wake of the Boston Marathon bombings, conspiracy theories claimed that the “real” perpetrators were Navy Seals or other US government agents.

Examining the “temporal signatures” (tweet volume over time) of the rumors revealed a couple of interesting features. First, the number of tweets spreading a rumor was almost always far higher than the volume of tweets correcting it. Second, conspiracy theories looked different from other rumors. Clickbait and sensemaking rumors took off quickly and then faded with a rapid, exponential decay. But conspiracy theories didn’t decay in the same way. They persisted for weeks and months after the event and would repeatedly resurface over time.

Finally, conspiracy theory rumors had a high “domain diversity” (Maddock et al. 2015)—a measure of the distribution of websites that were linked to within tweets. In other words, there were far more domains cited, and they were a whole lot quircker than the domains cited in the other rumors.

Conspiracy Theories as a Window into the Alternative Media Ecosystem

In 2013, conspiracy theories seemed like a small part of the conversation. But by 2015, conspiracy theorizing was becoming an increasingly salient part of the online discussion, particularly around man-made crisis events (e.g., acts of terrorism and mass shooting events). An online community began to repeatedly claim that tragic events were not as they seemed and that they were hoaxes perpetrated by “crisis actors” or “false flag” events with hidden perpetrators.

The graph below (figure 1), which was created using user co-sharing patterns, depicts the information ecosystem that supported conspiracy theory rumorizing on Twitter in 2016 (Starbird 2017). The nodes are web domains, connected when the same user sends tweets.
linking to both websites. Red nodes are the domains that supported the conspiracy theorizing. They include a variety of clickbait, conspiracy-laden sites, partisan news sites, and some other murkier domains—including state-sponsored media outlets tied to Russia and Iran. Blue nodes are domains that hosted content attempting to debunk the conspiracy theories. Yellow nodes contained factual articles that were cited by conspiracy theorists as evidence for their theories.

A manual content analysis of the different web domains revealed this conspiracy theory ecosystem (the red nodes) to be supporting a variety of different conspiracy theories and pseudo-scientific claims as well as diverse claims about powerful people controlling world events—and a sort of all-encompassing conspiracy theory “frame” through which to interpret each new event. We theorized that the structure of an “alternative media ecosystem” had developed around and functioned to reinforce that corrupted frame.

Conspiracy theorizing and disinformation were sinking into the fabric of the internet, the recommendation algorithms, and the networks of friend and following relationships on social media in ways that would become increasingly hard to unwind.

**Russian Interference: A Coordinated Disinformation Campaign**

In 2016, my colleagues and I were studying “framing contests” within the #BlackLivesMatter discourse. As part of that analysis, we created a retweet network graph of Twitter users who participated in conversations around shooting events where users employed either the #BlackLivesMatter hashtag or the #BlueLivesMatter hashtag. The graph revealed two separate communities or “echo chambers” on either side of the conversation: pro-#BlackLivesMatter on the left (where most of the accounts were also politically left-leaning or “progressive”) and anti-#BlackLivesMatter on the right (where accounts were consistently politically right-leaning or “conservative”). Our initial paper explored how those two different online communities created and spread very different frames about police shootings of Black Americans (Stewart et al. 2017).

We published our study in October 2017. A few weeks later, Twitter (under pressure from a US congressional investigation) released a list of accounts associated with the Internet Research Agency in St. Petersburg, Russia, which was running disinformation operations online, targeting US populations during the same time period as our #BlackLivesMatter research. Scanning the list, I realized that I recognized some of those accounts. We had featured several in our paper.

Concerned about the implications, we cross-referenced the list of Russian trolls against our retweet network graph to see where they were in the conversation. At the time, the results surprised us (figure 2). The Russian trolls had infiltrated both “sides” of the #BlackLivesMatter discourse on Twitter. A few were among the most influential accounts in the conversation. One troll account on the left was retweeted by @jack, then-CEO of Twitter. Several orange accounts on the right had integrated into other online organizing efforts on the conservative side.

Ahmer Arif, a PhD student at the time, conducted in-depth qualitative research on these Russian troll accounts (Arif et al. 2018). He found several that enacted multidimensional online personas, across platforms, that played on stereotypes of Black Americans (on one side) and white US conservatives (on the other). They were impersonating activists and also modeling what online activism looked like—reflecting norms but also, to some extent, shaping them. Often their content wasn’t superficially problematic, for example, tweeting about “strong Black voices” on the left or support of US veterans on the right. In other places they were sowing and amplifying division. Some of their content was among the most vitriolic content in the space (e.g., advocating for violence against police on the left and using racial epithets on the right). In a few places, we can see them holding arguments with themselves—like a puppeteer, having one of their accounts on the left “fight” with one of their accounts on the right.

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The events of 2016 led to increased awareness of our collective vulnerabilities to manipulation on social media. In the aftermath, there were numerous media articles and research studies documenting those weaknesses, as well as considerable work by social media platforms to attempt to address them. When we reflect on the story of online disinformation in 2016, we often think of it, predominantly, as foreign in origin, perpetrated by inauthentic actors (or fake accounts), and coordinated by various agencies in Russia. That was not the whole story, but it was a simple one that allowed researchers, media, and platforms to focus on outside actors and top-down campaigns.

The 2020 Election: Participatory Disinformation
Disinformation around the 2020 election—specifically the effort to produce and spread misleading claims of voter fraud—looked very different. That effort was primarily domestic, largely coming from inside the United States. It was authentic, perpetrated in many cases by “blue check” or verified accounts. And the 2020 disinformation campaign wasn’t entirely coordinated, but instead largely cultivated and even organic in places, with everyday people creating and spreading disinformation about the election.

We will have to work to understand both the risks of generative AI as well as the possibilities of employing it to support more trustworthy information spaces.

In recent work, my colleagues and I have attempted to explain how this campaign worked (Prochaska et al. 2023; Starbird et al. 2023). First, political elites set a false expectation of voter fraud. For example, in a tweet posted in June of 2020, then-President Trump claimed the election would be “rigged,” that ballots would be printed (and ostensibly filled out) in foreign countries, and that this would be “the scandal of our times.” This “voter fraud” refrain was repeated over and over again in the months leading up to the election. It became a frame through which politically aligned audiences would interpret the events of the election. And it led to a corrupted sense-making process, where everyday people misinterpreted what they were seeing and hearing about as “evidence” of voter fraud, eventually generating hundreds of false claims and misleading narratives.

Our research team conceptualized the spread of “voter fraud” rumors about the 2020 election as participatory disinformation, with elites (in media and politics) collaborating with social media influencers and everyday people to produce and spread content for political goals. Participatory disinformation takes shape as improvised collaborations between witting agents and unwitting (though willing) crowds of sincere believers. These collaborations follow increasingly well-worn patterns and use increasingly sophisticated tools. We theorize that participatory disinformation is becoming structurally embedded into the sociotechnical infrastructure of the Internet.

Conclusions
So what next? Unfortunately, the challenges of understanding online rumors and mitigating harmful disinformation and manipulation remain. On top of the dynamics described here, there are additional concerning trends. Advances in generative AI threaten to supercharge the spread of deceptive content. Under political pressure, many social media platforms have stepped back from their efforts to address misinformation and combat manipulation. Platform transparency is waning as well. The kinds of analyses I describe above are no longer possible—at least not on an academic budget. Researchers like myself are under attack from online conspiracy theorists and political operatives (Nix et al. 2023).

But I am still hopeful that we can turn the tides on the online disinformation problem. With challenge comes opportunity. Researchers from diverse fields will need to develop new methods to study new platforms under new constraints. We will have to work to understand both the risks of generative AI as well as the possibilities of employing it to support more trustworthy information spaces. And we will need to design, deploy, and evaluate potential remedies—based on a nuanced understanding of the evolving, participatory nature of the problem. We will not solve all of this with a single new design feature, platform, policy, or educational program. It is going to require all of the above and more. But I encourage those working in this space to keep chipping away.
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Sustainability in lithium production is not merely a desirable goal; it is an imperative for fostering a greener future.

As societies worldwide pivot towards electric vehicles, lithium-ion batteries stand as the cornerstone of energy storage. Mining, often met with societal apprehension, becomes an inextricable part of this transition, unearthing raw materials like lithium and boron. These elements are the lifeblood of the green revolution, enabling the production of batteries that drive the clean energy paradigm. Striking a delicate balance between meeting rising demand and minimizing social and ecological impact is imperative. Thus, understanding and optimizing the processes involved in mining and lithium processing becomes not just a technological necessity but a moral obligation in order to forge a sustainable path towards a decarbonized future.

Though lithium is understood to be an integral part of the energy revolution, the United States does not currently have a ready supply. Several lithium development projects are in the western United States. One of the most advanced projects is Ioneer’s Rhyolite Ridge Lithium-Boron Project located in Esmeralda County, Nevada (figure 1). The project will produce over 20,000 metric tons per year of lithium carbonate (quadrupling the current US domestic production capacity) and 174,000 metric tons of boric acid. Lithium carbonate is a key ingredient in battery production for electric vehicles, and stationary energy

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storage is critical to the ongoing global electrification and decarbonization effort. Production from the project will be sufficient for approximately 400,000 electric vehicles per year. Boric acid is also crucial for decarbonization and is used in electric vehicle (EV) components such as permanent magnets and solar panel specialty glass (Fluor Enterprises, Inc. 2020).

**Rhyolite Ridge at a Glance: Sustainable Processing**

The Rhyolite Ridge Lithium-Boron Project not only produces critical minerals required for the ongoing decarbonization efforts, but the selected technologies enable the production of these minerals in a sustainable manner. The development will consist of open-pit mining, a production facility, and a sulfuric acid plant.

A high-level description of the processing facility with major unit operations is shown in figure 2. Once received by the plant, the ore will go through different crushing stages to obtain a suitable size for leaching. This later stage will consist of seven different vat leach tanks fed from the bottom up with concentrated sulfuric acid as the leaching solution. The resulting pregnant leach solution (PLS), containing solubilized lithium and other elements, will be sent to the chemical processing plant, where it will go through a combination of chemical purifications, crystallization, and evaporation stages to obtain final purified technical-grade lithium carbonate and boric acid.

This entire process is done in a sustainable manner, with all the required power being produced on-site through a CO2-free process by recovering heat from exothermic reactions of sulfur combustion in the sulfuric acid plant. An autonomous haul truck fleet will be used in the open-pit mine, and several automated process control systems will be implemented to streamline the process and mining operations. This facility aims to achieve zero discharge by recycling and reusing about 50% of
the water within the facility.

Ongoing operational improvement efforts are being conducted to reduce reagent consumption. This will reduce the burden associated with logistics and transport. These improvement efforts have also identified potential alternative technologies that will further reduce the overall water consumption. Additionally, studies are ongoing for the monetization of byproducts like magnesium and potassium sulfates. This will reduce the environmental footprint of the project particularly for carbon, water, and the physical footprint of the spent ore storage facility. (Fluor Enterprises, Inc. 2020).

A Greenfield Has Been Located—Now What?

Before mining can begin, an extensive permit process is required. As the project is situated on US federal land,ioneer is seeking approval from the federal government to begin construction at Rhyolite Ridge under the National Environmental Policy Act (NEPA). This NEPA process is administered by the Bureau of Land Management (BLM). In total, approximately thirty permits and licenses must be obtained prior to the commencement of construction and operation. Of the thirty approvals, the most significant are the state air permit, the state water permit, and a positive federal record of decision (ROD). The ROD incorporates an environmental impact statement (EIS) and is the culmination of the BLM’s NEPA process. The steps of the NEPA process are shown in figure 3.

What Happens to the Electric Vehicle Supply Chain and Sourcing in the Meantime?

Over the next decade, the growing demand and difficulty in bringing on supply present challenges, especially for the domestic supply chain. The soaring demand for lithium, fueled by the rapid expansion of EVs and the proliferation of stationary storage applications, highlights the existing fragility of the supply chain. As the world gravitates towards cleaner energy solutions, concerns arise regarding the insufficient capacity of lithium production to meet escalating requirements globally. The strain on the supply chain poses potential bottlenecks, impacting the transition to sustainable technologies and underscoring the urgent need for strategic investments and innovations to fortify the lithium supply chain against the burgeoning demand in the years ahead.

Global EV battery demand increased by about 65% in 2022, reaching around 550 GWh, about the same level as EV battery production. The lithium-ion automotive battery manufacturing capacity in 2022 was roughly 1.5 TWh for the year, implying a utilization rate of around 35% compared to about 43% in 2021.

Battery demand is set to increase significantly by 2030, reaching over 3 TWh in the stated policies scenario (STEPS) and about 3.5 TWh in the announced pledges scenario (APS). To meet that demand, more than fifty gigafactories (each with 35 GWh of annual production capacity) would be needed by 2030 in STEPS in addition to today’s battery production capacity. This increase is close to the 65 new gigafactories needed to meet 2030 demand in the APS. According to Benchmark Mineral Intelligence (as of March 2023), the announced battery production capacity by private companies for EVs in 2030 amounts to 6.8 TWh, plenty sufficient to meet demand in both STEPS and the APS. In the net zero by 2050 (NZE) scenario, battery demand reaches over 5.5 TWh in 2030 (figure 4). Assuming an average utilization rate of battery production facilities of 85%, the announced capacity in 2030 narrowly covers what is needed in the NZE scenario (IEA 2023).

China is expected to dominate demand for EV batteries up to 2025, in both STEPS and the APS. However, in the APS, China’s share of EV battery demand declines to about 35% in 2030 from over 55% in 2022, due to significant growth in EV sales in the United States, Europe, and other markets (figure 5).

Responsible Mining and Sustainability

Like many other industries, mining is subject to increasing scrutiny related to sustainability and responsible practices. The first layer of responsible mining comes from compliance with strict environmental, safety, and governance regulations. Recall that the Rhyolite Ridge Lithium-Boron Project requires thirty permits and licenses to commence

construction and operation. Typically, mining projects in the United States must have air, water, waste, reclamation, and land use permits. These permits dictate activities such as effluent and emission limitations, discharge volumes, and bonding for land restoration.

In recent times, a push for adhering to third-party standards outside of regulations has also been required. One of the typical third-party standards is the ISO14001 Environmental Management System. This system organizes the documentation of a company to demonstrate compliance and goal setting for environmental improvement. The system is audited periodically to ensure its effectiveness and adherence to the ISO14001 standard (IOS 2015).

From there, companies can adhere to sustainability management standards. An example is the Towards Sustainable Mining Initiative. Using this type of standard, a company must meet criteria put forth by the organization. In this case, member companies must follow protocols for activities such as indigenous and community engagement, water management, biodiversity management, and diversity and inclusion. The companies must self-report and are also audited by a third party.

Finally, companies adhere to sustainability reporting frameworks such as the Global Reporting Initiative (GRI). Reporting above and beyond compliance requirements traditionally covers a myriad of topics from diversity to cybersecurity, environmental performance, and employee safety (Global Reporting Initiative 2023). The reporting is published on a periodic basis, usually in a sustainability report.

**Conclusion**

The interplay among lithium supply, mining practices, and sustainability underscores the pivotal crossroads at which our pursuit of decarbonization stands. As the global auto industry shifts towards electric vehicles and stationary grid storage becomes more prominent, the demand for lithium will grow significantly. Given the need to extract lithium, the mining industry finds itself at the forefront of environmental and social considerations. Balancing the need for resource extraction and refining with the conservation and protection of the environment requires innovative and sustainable mining practices. The vulnerability of the lithium supply chain reveals the urgency of investing in responsible sourcing. Sustainability in lithium production is not merely a desirable goal; it is an imperative for fostering a greener future. To satisfy these objectives, an integration of environmental stewardship, social responsibility, and technological advancements will be the linchpin for achieving a resilient and sustainable lithium supply chain that propels us towards a cleaner, low-carbon energy landscape.

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Earth’s mineral resources have driven the advancement of civilization for the last five thousand years—and we have become dependent on an ever-increasing volume and variety of them.

Mineral Resources
The Material Basis of Civilizations

Isabel Fay Barton

Throughout history, the extent of humans’ and societies’ achievement has depended on what materials are available. The most consequential of these, such as metals and fuels, have been derived from mineral resources, and their spread through society has created massive but invisible dependence on continued mineral resource supplies. Present technology depends on a larger amount and wider range of minerals than ever before (figure 1). This article provides a brief techno-historical summary of how our dependence on mineral resources reached its current unprecedented level.

The Earliest Mineral Dependence

For most societies, mineral resource dependence began with the Bronze Age (ca. 3200 BC in the Middle East, later in other regions). Copper, gold, and other mineral resources had been in use before as status and religious symbols, but bronze was the first material whose properties conferred a significant practical advantage over stone, antler, or flint. Bronze, an alloy of copper with arsenic or tin, is tough, strong, and holds a good edge. Most importantly, it melts at a relatively low temperature and can be cast in large lots with standard sizes, enabling the world’s first mass production.

These properties of bronze changed the military and geopolitical landscape. With mass-produced standard weapons and armor, identically armed soldiers could operate as units with collective and individual advantages over
advocates armed with stone. This invention of the organized army contributed to the rise of empires. Particularly around the ancient Middle East, empires such as the Akkadians and Babylonians dominated their regions by organizing the production, working, and application of bronze weapons and armor (Gabriel and Metz 1991). However, maintaining power became conditional on maintaining supplies of copper and tin. In parts of the ancient Middle East in the second millennium BC, trade in both metals was tightly controlled by the government as a way of controlling the arms supply (Mirsky 1982). An exception to the Bronze Age pattern was sub-Saharan Africa, where copper and iron were used intensively prior to bronze, and iron became the metal on which most societies depended (Killick 2016).

The Intensification of Mineral Resource Dependence

During most of the Bronze Age, bronze remained relatively scarce. Most of society continued using Stone Age materials for tools and farm implements until copper and tin mining and bronzemaking had reached a very large scale. But even then, metals remained too rare and expensive for most people to have more than a small amount.

This only began to change with the discovery of iron smelting. Though ancient iron was inferior to well-made bronze in hardness, corrosion resistance, toughness, and castability, it was far cheaper since iron ore deposits are orders of magnitude more common than copper or tin. Unlike bronze, iron was so widely available that archaeometallurgists call it the “democratic metal.” The average amount of metal to go around was still small—an estimated 1.5 kg of iron per capita per year during the Roman-era peak in pre-industrial production—but was still several times more than ever before (Sim and Ridge 2002).

The spread of iron tools began to raise agricultural and industrial production. This in turn supported population growth but also required iron-using societies to maintain or expand iron ore supplies to maintain the population and standards of living. Many also used bronze alongside iron and made currency from one or more of gold, silver, or copper. As metal use began to pervade the economic, social, and industrial (as well as military) fabric of societies, mineral resource dependence ratcheted up again.

The Extension of Mineral Dependence

In general, Iron Age societies’ mineral dependence was intensive but not extensive. Their suite of necessary mineral resources consisted of iron, copper, tin, gold, silver, lead, zinc, mercury, and salt. Many societies thrived without one or several of these. But, though few, these mineral resources were intensively used, and even short-term supply interruptions could devastate economies and industries. To cite two instances, the exhaustion of the Central Asian silver mines caused a major financial crisis in China, and the Persian takeover of western Asia’s gold mines nearly strangled the gold-based Byzantine economy (Blanchard 2003).

Mineral dependence intensified over the first to early second millennia AD, but in most societies, it did not become much more extensive. The main exception was medieval Eurasia, where new minerals came into use (figure 1) and then became vital as the population increased and use of the new resources became more common and intensive. Of the numerous examples, perhaps the two most consequential were nitrates and coal. Nitrates formed the basis for roughly 75% of gunpowder, which originated in China and slowly spread west, reaching western Asia and Europe around the fourteenth century AD. There it found a ready welcome in a region that probably had the highest frequency of wars per unit
area of any place on earth at the time. As the first material since the Bronze Age to confer a nearly insuperable military advantage on the possessor, gunpowder became popular, and the associated technology improved rapidly. By the late 1600s, no army from Europe to western Asia was competitive without a large, steady, and well-organized supply of nitrates. Associated advances in gunpowder technology would lay the foundation for Europe’s global empires later.

Coal-burning also started to become common in Europe during the fourteenth century. The combination of high population density, cold winters, and centuries of charcoal burning had deforested the region, and wood and charcoal became rarer and more costly. As a cheaper substitute, the poor began to burn lumps of coal washed up on beaches or picked up on hillsides. This marked the first use of minerals as fuel. By 1700, British inventors began using the heat to boil water to steam and using the steam to push a piston. Coal, as the only fuel that combined high-energy density, ready availability, and a cheap price, kicked off the Industrial Revolution.

This was, above all, a revolution in the amount of power at human disposal (Smil 2017). Coal made power abundant, portable, and cheap for the first time in history, enabling a rapid rise in per capita power use (figure 2). Steam-powered factories replaced the handicraft system of manufacture, boosting output and decoupling it from the number of workers. The per capita GDP of industrializing economies soared compared to those that remained on a traditional or agrarian basis (Malanima 2016). Industrial nations’ manufactures began to dominate the global economy, while their industrialized and gunpowder-based military machines dominated their territory. But maintaining that dominance became conditional on maintaining large supplies of coal, as well as the iron, nickel, chrome, and other ferroalloy elements used in making the machinery and, of course, nitrates. Mineral resource dependence skyrocketed, increasing further as electricity required unprecedented amounts of copper and battery metals.

### Mineral Resource Reliance Today and in the Future

From these beginnings, society’s mineral resource dependence has continued to increase in intensity and extent. Technologies that modern people take for granted, such as computers and cell phones, are predicated on an invisible, but vast and increasing, supply of materials mined from the earth’s finite mineral resources. Moore’s Law offers an example in microcosm. Between the 1980s and the early 2000s, the number of chemical elements required to make an advanced computer chip went from twelve to more than sixty (USGS 2017). The properties of gallium, platinum-group metals, and other elements enabled transistors to be made ever smaller without loss of performance, so that more and more could be packed onto a chip. The observed exponential rise in computing power is, at its base, a consequence of a nearly exponential rise in the number of mineral resource-based materials used to make computers. Virtually all modern technology follows a similar pattern of obtaining higher performance by extending dependence on mineral resources (Graedel and Miatto 2022).

It is rare for a society to lower its dependence on mineral resources. Depressions and dark ages are the most common reasons. Less drastic but smaller in scale are decreases in dependence on individual mineral resources. For example, after the late 1800s, cyanidation replaced mercury-based methods of extracting gold and silver from ore, mostly eliminating society’s need for mercury (Habashi 2016).
Otherwise, dependence usually shifts rather than decreasing. Green energy, for instance, is effectively the replacement of a consumable, short-lived, unrecyclable type of mineral resource (fossil fuels) with a durable, long-lasting, and moderately recyclable variety (metals). While this improves sustainability, the shift does not actually reduce dependence on mineral resources (Hammond and Brady 2022).

In the long run, whether technology and standards of living can continue to advance will depend on whether adequate supplies of mineral resources continue to be available. At current levels of consumption, this is questionable. Each year we mine and add to circulation about as much metal as is contained in one world-class copper deposit, for example, which the earth can take millions of years to regenerate. The only long-term sustainable solution is to balance society’s demands with the earth’s finite supplies.

**Conclusions**

Since the Bronze Age, exploitation of the earth’s mineral resources has provided metals, fuels, and industrial minerals to enhance human capability. The unique physical, chemical, and electromagnetic properties of these materials have formed the basis for advancing technology, spreading industrialization, growing populations, and improving standards of living for the last five thousand years. But as mineral resources have become essential, we have also become dependent on an ever-increasing volume and variety of them. In the future, as in the past, what humans will be able to accomplish—individually or as societies—will continue to be a function of what mineral-derived materials are available for them to use.

**References**


To keep up with the ever-expanding societal demand for metals, responsible stewardship in mining and the circular economy are essential.

Mass Balance and the Circular Economy

The cause of the recent interest in critical materials and minerals can be found in figure 1, which shows the fundamental mass balance equation and a representation of the circular economy. With regard to the sourcing of raw materials, only mining (primary) or recycling (secondary) sources represent feasible means of introducing raw materials into the circular economy. The recovery of materials
after use is critical to maximizing value, either through reuse, remanufacturing, or recycling. Those materials not subject to recovery are refused back into the biosphere. The recovery of true end-of-life materials is subject to the economic and technological barriers to extracting value from waste through recycling. It is often more cost-effective to dispose of something than to recycle it. These materials are often low grade, highly heterogeneous, and more complex than the ores they replace.

As a case study, copper illustrates the complexity of this issue. The world population has increased from about 2.5 billion in 1950 to slightly over 8 billion in 2022. In the same period, copper utilization rose from about 1.2 kg per person to about 3.3 kg (The World Copper Factbook 2023). Not only is the population increasing, but the consumption per person is also increasing. In considering both the per capita use and population, the quantity of required copper has increased by 880% from 1950 to 2022. It becomes clear from the mass balance equation shown in figure 1 that it is impossible to recycle our way into prosperity. The circular economy requires mining to prime the system. This is further compounded by the fact that the ten-year recycling input rate for copper is about 31% (The World Copper Factbook 2023). Thus, the problem is twofold: insertion into and loss prevention in the circular economy.

FIGURE 1 Figure depicting mass balance in the context of the circular economy (adapted in part from Jawahir et al. 2016).

The Straight and Narrow Path

This leads to a paradox that might be termed the “straight and narrow path.” It is as though the mining industry travels a road bounded by two competing forces. On the one hand, you have what society requires, often termed the “social license to operate.” This can be described as the sum of all the societal forces acting on the mine. It ranges from regulatory requirements to politics and community approbation. It includes intangibles such as reputation and goodwill. It is the permissions and expectations that society places upon the mine to allow its commencement and continued operation. On the other hand, you have what society demands, manifested by the market price for materials. Ever present are the competing market forces of environmental sustainability pitched against metals demand, causing the pendulum to swing.

Nowhere can these juxtapositions be observed more clearly than in the examples of mining around Yellowstone National Park. By way of background, in the ‘90s the Clinton administration spearheaded agreements for federal lands to ban mining in the area. Although successful, this still left the opportunity of mining private lands. Just this year, a creative solution was announced where environmental groups block a gold mine by pur-
chasing it (Grandoni 2023). The societal value of preservation was leveraged against market forces to reach an economic solution. However, this does not fundamentally resolve the problem of “if not here, then where?” Much like a dammed river, an eventual outlet for pent-up demand will be found and sometimes in locales where economic forces outweigh ethics and environmental considerations.

**Ecosystem Realities**

To evaluate the interplay among primary metals sources, over 100 “customer discovery” interviews in the mining and recycling space were done as a part of the NSF I-Corps entrepreneurial training program. Its purpose is to determine, through direct consultation with potential customers, the reality of the need and to provide concrete evidence that the proposed solutions to those needs are in fact valid. The realities of the recycling ecosystem are shown in the ecosystem map below (figure 2), which represents the copper recycling ecosystem. This figure was created after interviewing suppliers such as e-waste processors, sorters, shredders, and wire choppers. Also included were companies specializing in smelting and the customers for produced semifinished goods. It depicts a simplified representation of the interdependent material flows.

The results were surprising. The industry is multifaceted and appears to be going through a period of consolidation, from various regional and familial entities to larger corporations. A key finding was the distillation of what appear to be six fundamental competitive advantages: 1) access to supply (also known as book of business), 2) logistics, 3) solution value to customers (such as IT asset destruction and recovery [ITAD/ITAR]), 4) asymmetry of information, 5) technology and/or process, and 5) access to capital. Of note is the asymmetry of information, where a competitive advantage exists due to having privileged or proprietary information. In our interviews, this opacity was fascinating as a key competitive advantage of the ecosystem. The economic realities of low-cost overseas solutions combined with modernization costs led to a period, from 2002 to 2023, in which there existed no smelters (a mixed-metal pyrometallurgical process) in the United States capable of processing secondary materials. Even though primary material smelters exist in the United States, not all smelters can handle the same feed material form factor. Further, the downstream customers can seamlessly alternate between mined and recycled materials.

**A Path Forward**

In view of the interplay between primary and secondary materials, often the answer to current problems is technological progress. At the University of Kentucky Mining Engineering Department, several unique projects have been launched addressing sustainability in the circular

![FIGURE 2 Simplified ecosystem map showing the copper recycling ecosystem of suppliers, competitors, and customers.](image)
economy and in mining. One of these, sponsored by the NSF, is titled “SMaRT (Sustainable Materials and Recovery Technologies) for E-waste” and aims to use a novel and green technology to recover copper and precious metals from e-wastes in an environmentally friendly and closed-loop fashion, as shown in figure 3. In like manner, a first-of-its-kind heap leach pad for coal refuse was established to study the feasibility of recovering rare earth elements (REEs) via heap and tank leaching utilizing the bio-oxidation of pyrite (see figure 4).

Conclusions and a Call to Action

As we look to the future in addressing how we will meet our growing consumption of materials while balancing ecological sustainability, it is clear that this is a truly multidisciplinary endeavor. From a mass balance perspective, we cannot recycle our way to prosperity. A true solution will require the balance of exploration, production, and sustainability. It will require the very best that we, as engineers, have to offer. Yet persistent is
the problem of too few to fill so great a demand. It may be said of the industry, to quote Winston Churchill, “Never has so much been owed by so many to so few.” The opportunities are immense, the challenges are real, and the “straight and narrow path” becomes increasingly tenuous. So, the call comes. It calls to me. It is calling to you. Come bring the best you have. Join us, and together we will meet this challenge. Let us walk this long road together.

References
A connected pharmaceutical supply chain offers the potential to revolutionize how drugs are developed, produced, and delivered to patients.

Transforming Pharmaceutical Supply Chains
A Connected Approach for Enhanced Drug Delivery

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The life science industry, especially the pharmaceutical sector, is pivotal in maintaining and improving public health globally. Recent data from the ASHP Drug Shortages Resource Center at the University of Utah Drug Information Services underscore a concerning shortage of 309 active drugs in the second quarter of 2023, marking the highest number in almost a decade (ASHP 2023).

Chemotherapy drugs are among the top five categories experiencing the most pronounced shortages. The shortages those drugs are facing are deemed the most severe by 57% of pharmacists, who describe them as "critically impactful," directly affecting patient care. More than 40% of healthcare system pharmacists report having to delay or cancel treatments or procedures due to drug shortages (ASHP 2023).

This scarcity has been further intensified by the global COVID-19 pandemic, emphasizing the pressing need for a robust and agile supply chain in the life science industry. This article delves into the imperative of a well-functioning healthcare supply chain. It explores the potential of connecting complex global supply chains using supply chain control tower (SCCT) technology within the life science industry to expedite drug delivery to patients.

Understanding the Healthcare Supply Chain
The reliance of Americans on medications is substantial. Around 45.8% of the US population has utilized prescription drugs within the last 30 days (Martin
et al. 2019), underscoring the critical necessity of ensuring the availability of medicines.

The healthcare supply chain within the life science industry is a complex network of processes and stakeholders involved in producing, distributing, and delivering pharmaceutical products to patients. The journey commences with sourcing raw materials and progresses through manufacturing, packaging, distribution, and ultimately reaching healthcare providers or patients (figure 1). Any disruption within this intricate network can severely impact patients’ health, highlighting the criticality of a well-coordinated and robust supply chain.

A seamlessly connected healthcare supply chain enables real-time information exchange and collaboration among various stakeholders, including manufacturers, distributors, healthcare providers, and patients. Biopharmaceutical companies, through the integration of centralized technology and SCCTs, can bridge gaps in the supply chain and optimize the flow of products from raw materials to timely delivery to patients. This integration is pivotal in enhancing the accessibility and availability of essential medications, ultimately improving overall healthcare outcomes.

Improved communication and collaboration among the nodes constitute a primary benefit of a connected supply chain. A seamless flow of information, from patient demand to manufacturing capacities, empowers stakeholders to respond swiftly to changing circumstances and unexpected events. This enhanced communication ensures that fluctuations in demand are addressed in a timely manner, preventing the unavailability of medicines for patients. Moreover, a connected supply chain fosters flexibility, enabling rapid adjustments and adaptations to meet evolving market needs and unforeseen challenges.

Establishing a connected supply chain allows manufacturers to align their operations more closely with patient demand. Real-time communication of demand needs from patients to manufacturers enables a demand-driven approach to supply and demand planning. It ensures that the manufacturers produce the right quantities of medications and distribute them promptly, minimizing excess inventory and reducing the risk of drug shortages. A fluid and responsive supply-and-demand planning process is crucial to meeting patients’ needs and expectations.

Connecting the global supply chain in the life science industry aims to prevent drug shortages and ensure patients can access the required medications. A well-coordinated supply chain, facilitated by centralized technology and SCCTs, significantly contributes to achieving this objective.

**Centralized Technology and SCCTs**

Centralized technology forms the backbone of the healthcare supply chain, connecting its nodes and enabling real-time data collection, analysis, and dissemination. In this interconnected network, SCCTs act as centralized command centers, providing a comprehensive view of the supply chain and facilitating effective monitoring and management of operations. Through the utilization of advanced analytics and predictive modeling, these control towers can anticipate demand, optimize inventory levels, and enhance supply chain resilience.

In the evolving landscape of healthcare supply chain management, centralized systems, particularly SCCTs, signify a paradigm shift. These systems amalgamate various components and cutting-edge technologies to form a unified and interconnected supply chain ecosystem.

At the heart of the SCCT lies a sophisticated system with critical components that collectively enhance its
ability to efficiently manage complex supply chains. The centralized data hub acts as the primary repository, akin to a cell’s nucleus, housing all vital supply chain data. This hub offers a comprehensive view of supply chain dynamics by aggregating, organizing, and managing the extensive data generated, collected, or utilized.

Fundamental aspects of managing intricate supply chains are effective communication and collaboration. SCCTs are equipped with collaboration tools that facilitate seamless communication and information sharing among stakeholders. The tools streamline processes, ensuring alignment among all involved parties and ultimately enhancing overall efficiency.

One of the pivotal features of SCCTs is the integration of advanced analytics, including machine learning and predictive analytics. Stakeholders benefit from actionable insights derived from vast amounts of supply chain data, enabling informed decision-making by forecasting demand, predicting disruptions, optimizing inventory levels, and more.

**Connecting the global supply chain in the life science industry aims to prevent drug shortages and ensure patients can access the required medications.**

A robust and reliable infrastructure serves as the backbone of SCCTs, encompassing high-performance servers, secure networks, and advanced computing capabilities. This infrastructure is essential for smooth operations and rapid data processing, enabling real-time decision-making—a critical aspect of efficient supply chain management.

Security measures are paramount within SCCTs to safeguard sensitive healthcare data. Rigorous implementation of encryption, access controls, and continuous monitoring ensures data integrity and confidentiality, fostering trust and maintaining privacy in healthcare information handling within the supply chain.

The role of technology enablers in the effectiveness of SCCTs cannot be overstated. They have revolutionized supply chain management processes. Artificial intelligence (AI) acts as a cognitive powerhouse within SCCTs, analyzing data patterns, predicting future scenarios, and automating routine tasks, significantly boosting supply chain efficiency with intelligent decision-making capabilities.

Complementing AI, machine learning enables systems to learn and improve from experience, contributing to more accurate and efficient decision-making over time. The integration of the Internet of Things (IoT) in supply chains transforms the traditional approach into a dynamic, real-time ecosystem. IoT facilitates live updates from various touchpoints within the supply chain through interconnected devices equipped with sensors and communication capabilities. This connectivity revolutionizes data collection and dissemination, providing invaluable insights for improved decision-making within the supply chain.

**The Impact of Centralized Systems on the Healthcare Supply Chain**

Integrating centralized systems and SCCTs into the healthcare supply chain landscape yields profound and far-reaching impacts, transforming how the supply chain is managed and ensuring enhanced efficiency, agility, and patient-centric outcomes.

Benefits of a connected supply chain include the ability to leverage real-time monitoring and data analytics to track the movement of pharmaceutical products across the supply chain. Advanced analytics, including AI and machine learning, provide actionable insights into demand patterns, enabling better production planning and inventory management.

A connected supply chain optimizes inventory levels by facilitating a continuous flow of information. Manufacturers can align their production with actual demand, reducing excess inventory and minimizing the risk of overstocking or stockouts, ultimately improving cost efficiency and ensuring critical medications’ availability.

Collaboration with suppliers and partners is encouraged, promoting a cohesive and mutually beneficial relationship. Real-time demand forecasts and production schedules shared with suppliers ensure a steady and timely supply of raw materials, fostering trust and reliability within the supply chain ecosystem.

The objective of a connected supply chain is to prioritize patients’ needs. By integrating patient data and feedback, manufacturers can tailor production to match specific patient requirements, ensuring timely medica-
tions meet individual patients’ unique needs and promoting better health outcomes.

The interconnected nature of a connected supply chain enhances adaptability and resilience in the face of unexpected events or disruptions. Rapid communication and collaboration among supply chain nodes enable swift adjustments to production schedules, distribution routes, or inventory levels.

In a study conducted by Accenture, organizations implementing supply chain control towers have been shown to achieve substantial benefits: a 5% reduction in logistic costs, a notable 20% enhancement in labor efficiency, a 15% decrease in inventory, and a significant 15% reduction in waste through destruction, donation, or discount (Kumar et al. 2022).

While the concept of a connected supply chain holds immense promise, successful implementation requires addressing specific challenges and considerations:

- Increased data sharing across the supply chain raises concerns about data security and privacy. Robust cybersecurity measures and compliance with data protection regulations are essential to safeguarding the integrity and confidentiality of shared data.

- Integrating modern, centralized technology with legacy systems can pose technical challenges, necessitating substantial investment and expertise.

- Achieving proper connectivity necessitates active participation and collaboration from all supply chain stakeholders to overcome organizational silos and foster a culture of collaboration.

The pharmaceutical industry stands at the brink of a transformative era, driven by technological advancements and a growing realization of the need for efficient supply chain management. A connected supply chain represents a paradigm shift, offering the potential to revolutionize how drugs are developed, produced, and delivered to patients. Embracing this approach can enhance drug delivery efficiency, ensure patient satisfaction, and ultimately contribute to a healthier and more prosperous global community. While the journey towards a fully connected pharmaceutical supply chain may pose challenges, the benefits far outweigh the obstacles, making it a strategic imperative for the future of healthcare.

References
Human microphysiological systems have the capacity to vastly improve drug development by providing more physiologically relevant and predictive models for drug testing.

Engineering Human Organoids and Organ-on-Chips for Disease Modeling, Drug Development, and Personalized Medicine

Janny Piñeiro-Llanes and Rodrigo Cristofoletti

The pharmaceutical industry has been struggling to sustain sufficient innovation to replace the loss of revenues due to patent expirations for successful products and increasing R&D costs. A key aspect of this problem is the decreasing number of truly innovative new medicines approved by the US Food and Drug Administration (FDA) and other major regulatory bodies around the world (Paul et al. 2010). Among all the challenges the pharmaceutical industry faces, we argue that improving R&D productivity remains the most important. In fact, reducing the high attrition rates in drug development continues to be a key challenge for the pharmaceutical industry.

The Need to Improve Preclinical Translational Models to Decrease Attrition Rates in Drug Development

Despite the significant technological improvements in drug development in recent decades, attrition rates remain high. Although the number of failures of small-molecule drug candidates due to poor pharmacokinetic profiles diminished significantly in recent years, the failure rate is increasing because of efficacy and safety issues, which keeps the overall attrition rates high.

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An analysis of combined data on the attrition of drug candidates from AstraZeneca, Eli Lilly and Company, GlaxoSmithKline, and Pfizer revealed that the primary causes of failure for terminated compounds in phases 1 and 2 were clinical safety issues and inadequate efficacy, respectively (Waring et al. 2015). These compounds’ failure despite the satisfactory results from preclinical animal studies highlights the need to improve preclinical studies.

Animal studies have been a fundamental component of pharmaceutical research for many decades. While animal models provide insights into systemic effects and long-term consequences that are challenging to replicate in vitro, concerns about the capacity of animal data to anticipate human responses have emerged among scientists in the field. Indeed, an unparalleled study assessing the correlation between outcomes of preclinical models and results seen in early-phase clinical trials in oncology reported that animal toxicity did not show a strong correlation with human toxicity, with a median positive predictive value of 0.65 (significant proportion of false positive results or sponsor risk) and a negative predictive value of 0.50 (significant proportion of false negative results or patient risk) (Atkins et al. 2020). Furthermore, different genomic responses between animal models, including genetically modified mice, and humans suggest that molecular results from current mouse models developed to mimic human diseases may fail to translate directly to human conditions (Seok et al. 2013). For example, the genetic basis of Down Syndrome in humans is related to the trisomy of chromosome 21, whereas in the genetically modified Ts65Dn mice, the triplicated segment consists of ∼104 HSA21 orthologs as well as 60 centromeric MMU17 genes that are not triplicated in humans with Down Syndrome (Antonarakis et al. 2004). As a result, the prototypical compound RG1662 improved performance in cognitive tests in Ts65Dn mice, but a subsequent phase 2 clinical trial was stopped prematurely due to the lack of efficacy in humans (Erazo-Oliveras et al. 2023; Rudolph and Möhler 2014). Altogether, these examples demonstrate that relying only on animal data for predicting human responses to new drugs is an inadequate preclinical strategy.

New drugs in the development pipeline (e.g., monoclonal antibodies) are also becoming highly specific to human targets. Yet, the relevance of animal studies to assess drug efficacy and safety has been questioned, like in the case of a novel superagonist anti-CD28 monoclonal antibody (TGN1412) that directly stimulates T cells. In preclinical models, the stimulation of CD28 with TGN1412 resulted in transient lymphocytosis with no detectable toxic or pro-inflammatory effects. However, within ninety minutes after receiving a single intravenous dose of the drug, six healthy volunteers in a phase 1 study had a systemic inflammatory response characterized by a rapid induction of proinflammatory cytokines and accompanied by headache, myalgias, nausea, diarrhea, erythema, vasodilatation, and hypotension. Within twelve to sixteen hours after infusion, the healthy volunteers became critically ill, with pulmonary infiltrates, lung injury, renal failure, and disseminated intravascular coagulation (Suntharalingam et al. 2006). Besides the limited translatability of preclinical data, drug development is significantly affected by an unprecedented shortage of non-human primates for preclinical studies. A recent US National Academies of Sciences, Engineering, and Medicine report concluded that the situation is compromisingly critical for biomedical research now—and will continue to be well into the future (NASEM 2023). Overall, the combination of limited translatability of preclinical data and a deficiency of non-human primates for preclinical studies urge the development of alternative approaches in preclinical research.

Relying only on animal data for predicting human responses to new drugs is an inadequate preclinical strategy.

Human Microphysiological Systems: A Promising Alternative

In this context, developing human-relevant alternatives to animal testing could improve the translatability of nonclinical models. Human microphysiological systems (MPSs), such as organoids and microfluidic organs-on-chips, rapidly evolve as promising in vitro tools that can recapitulate human physiology by recreating key biological processes and disease states. MPSs combine microsystems engineering with cell biology, yielding cell-culture models that can display three-dimensional architecture, multicellular interactions, tissue-tissue interfaces, fluid flow, and organ-level mechanical cues (Roth 1979). The current working hypothesis in the field is that improving the physi-
ological relevance and complexity of the in vitro system would improve its predictive capacity. The obvious caveat is that the more complex an in vitro model is, the less compatible it will be with the high throughput screening concept, so there is plenty of room for engineering innovation.

Initially, the adoption of MPSs was primarily for preclinical safety (drug toxicology and metabolism), often for applications in a defined context of use requiring limited validation efforts. However, the MPS concept gained traction among regulators and rapidly transitioned from academic curiosity to regulatory acceptance. Indeed, on December 29, 2022, the FDA Modernization Act 2.0 was signed into law. The bill essentially incorporates MPSs into the US legal framework. This bill marked a significant shift in the regulatory paradigm, moving from interspecies translation to inter-systems and in vitro—in vivo extrapolation. Developing an MPS is a multidisciplinary effort that starts with the identification of the scientific question to be addressed and may encompass two parallel branches: 1) biology (e.g., cell source, biomaterials, scaffold), and 2) engineering (e.g., materials, microfabrication, sensors/actuators integration). Then, both branches are integrated, resulting in a microfluidic organ-chip device. The main feature of an MPS is its ability to recapitulate organ-level architecture and functionality, significantly differing from traditional cell-based assays. After functional validation of the MPS it can be applied to inform drug development and personalized medicine decisions (Rogal et al. 2022).

The main feature of an MPS is its ability to recapitulate organ-level architecture and functionality, significantly differing from traditional cell-based assays.

Organoids, which are self-organizing, 3D culture systems that are highly similar to—and in some cases, histologically indistinguishable from—actual human organs, are another type of MPS. One common feature of all organoids is that they are generated from pluripotent stem cells (PSCs) or adult stem cells by mimicking human development or organ regeneration in vitro.

The development of organoid technology is still in its infancy compared to established cell lines and animal models, with challenges still to be overcome. Nevertheless, the prospect of organoids complementing existing model systems to extend basic biological and medical research and drug discovery into a more physiologically relevant human setting is becoming ever more widely appreciated (Kim et al. 2020). For example, FDA-approved drug screening in patient-derived organoids demonstrates the potential of drug repurposing for rare cystic fibrosis genotypes. Briefly, cystic fibrosis is a rare hereditary disease caused by mutations in the CFTR gene. Pharmacotherapies termed CFTR modulators that rescue CFTR function have revolutionized treatment for approximately 85% of people with cystic fibrosis who carry the most prevalent F508del-CFTR mutation. Nevertheless, a large unmet need remains to identify new and affordable treatments for patients with CFTR mutations that are non-eligible for or non-responsive to CFTR modulators. Consequently, a recent study leverages the fact that CFTR function measurements in patient-derived intestinal organoids are associated with clinical features of cystic fibrosis to test drug repurposing in a personalized setting using a high-throughput screening. These CFTR function measurements are performed by means of the forskolin-induced assay, in which forskolin induces fluid secretion into the organoid lumen, resulting in rapid organoid swelling in a (near-to) complete CFTR-dependent manner (de Poel et al. 2023).

Our lab is highly interested in using MPSs to study genetic diseases and identify druggable targets. For example, understanding the molecular and cellular mechanisms downstream of the extra copy of chromosome 21 in Down Syndrome is one of our research interests. By using pluripotent stem cells from mosaic Down Syndrome individuals, we were able to develop in vitro twin organoids discordant for 21 trisomy, which would enable us to assess the perturbations of gene expression in trisomy 21 and to eliminate the noise of genomic variability. Additionally, we can derive matched organs for transcriptomics, proteomics, and pharmacology studies to shed some light on the source of multiple phenotypic variants among people living with Down Syndrome (figure 1).

Conclusion
Reducing drug attrition rates is of paramount importance in the pharmaceutical industry and has significant implications for both industry and public health. Specifically, improving efficiency, cost-effectiveness, and overall
drug development success is critical for the pharmaceutical industry’s sustainability, innovation, and ability to provide patients with safe and effective treatments. Moreover, it has a direct impact on public health by ensuring that patients have timely access to new and improved medications. MPSs have the potential to revolutionize drug development by providing more physiologically relevant and predictive models for drug testing. By doing so, they can significantly reduce high attrition rates, leading to more efficient, cost-effective, and patient-centric drug development processes.

References


Blood collection operations at the American Red Cross were improved through a dynamic programming approach that systematized the selection of collection sites.

Improving Blood Collection Operations at the American Red Cross

Approximately 29,000 units of red blood cells are needed every day in the United States, accounting for a total of 16 million annual blood component transfusions (American Red Cross 2023). The demand for blood transfusions continues to rise due to an increasing prevalence of chronic diseases, an aging population, and recent advancements in major therapies such as heart surgeries and organ transplants (Kasraian and Maghsudlu 2012). The margin between blood need and transfusable blood product availability is critically tight (Free et al. 2023), and warnings of blood shortages have recently received extensive media coverage.

How Blood Collection Works

The American Red Cross (ARC) is the primary provider of blood products within the United States, delivering over 40% of the nation’s blood supplies to over 3,000 hospitals. Furthermore, on an annual basis, it plays a critical role in responding to and assisting with the management of over 67,000 disasters worldwide. Operating through an extensive nationwide network, it relies on the dedication of over one million volunteers, employs 30,000 individuals, operates across 650 chapters, and serves 36 major regions.

Due to the limited supply and perishable nature of blood products, effective management of blood collection is critical for high-quality healthcare delivery. Blood collection procedures involve intricate processes. Donors contribute...
blood through either automated blood collection, known as apheresis, or standard whole blood donation. In the case of apheresis, a machine extracts specific blood components, like plasma or platelets, from the donor. Conversely, the more prevalent method is regular whole blood donation, where donors provide whole blood (Eder and Sebok 2007). Once collected, whole blood can be further divided into various components, including red blood cells, platelets, plasma, and cryoprecipitate.

Blood collection operations are complex and involve mobile collection sites. The selection of these locations and their associated collection timeframes is planned months in advance and determined based on factors like projected demand, the recency of prior visits to mobile sites, and the convenience of these locations for hosts. The duration of blood collection windows varies but generally spans between four and eight hours. The mobile collection vehicles are dispatched from the production facility early enough to commence collection at the start of the designated window. Once the collection period concludes, the mobile collection vehicle is packed up and returns to the production facility.

Cryo Collection: An Intricate and Costly Process

Cryoprecipitate (cryo) collection stands out as the most demanding among blood products. To generate cryo, the collected whole blood must be transported to a production facility. The plasma must be separated from red blood cells and then rapidly frozen into fresh-frozen plasma within eight hours of collection. In contrast, most other blood products allow a processing window of at least twenty-four hours from collection. This tight collection-to-processing timeframe for cryo complicates blood collection and production planning, presenting managerial complexities and practical challenges. For instance, to ensure compliance with the eight-hour constraint, additional courier services are often required to transport the collected whole blood back to the production facility promptly. Consequently, collecting blood for cryo is a more intricate and costly process compared to other blood products. Additionally, to produce cryo, special bags, known as cryo bags or triple bags, are utilized to collect whole blood. For other noncryo applications, less expensive bags, referred to as noncryo or double bags, can be used.

Mobile collection sites are typically designated as either cryo or noncryo sites for a given collection day, with the number of cryo sites depending on the Red Cross Headquarters’ weekly cryo collection target. The decision to designate sites for cryo collection does not impact the production of other blood products. Blood collected at mobile sites is transported back to the manufacturing facility by the end of the day, a process termed “end-of-day delivery.” However, for cryo sites, if the end-of-day delivery cannot meet the eight-hour collection-to-processing constraint, an additional midday pickup, typically provided by a courier company, is scheduled, incurring extra transportation expenses.

Cryoprecipitate collection stands out as the most demanding among blood products.

The selection of cryo-collection sites is usually made two days before the collection day, taking into account courier requirements, production planning, and staffing needs. If a site initially selected for cryo collection no longer requires cryo blood (e.g., the weekly production target has been met), cryo collection at that site can be canceled to avoid the midday pickup and its associated transportation cost. Cancellation may result in penalties and necessitate the use of more expensive cryo bags for noncryo products. The number of cryo units collected at a site is uncertain due to factors like donor no-shows, walk-in donors, and the success of cryo production from blood collected in cryo bags.

Meeting demand for cryo is very important because cryo plays a critical role in clotting and controlling massive hemorrhaging, and cryo is often used in the treatment of massive trauma and many major diseases, including metastasized cancers, cardiac diseases, hepatic failures, and organ transplants (Ness and Perkins 1979). Due to the advancements in major surgeries and treatments, the demand for cryo has been rapidly increasing (Curry et al. 2022). For example, from 2000-2010, the use of fresh-frozen plasma, the raw material for cryo production, increased tenfold and grew to more than 2.4 million units used annually in the United States (Gupte 2011).

Solving the Cryo Collection Problem

Our research team at Georgia Tech, in collaboration with colleagues at the American Red Cross, conducted a study in which we analyzed a regional-level cryo collection prob-
The problem faced by the ARC’s Southern Regional Manufacturing and Service Center (RMSC). The ARC’s Southern RMSC is one of the largest manufacturers and suppliers of blood and blood products, serving more than 120 hospitals in the southern United States. In particular, we focused on determining when and from which mobile collection sites to collect blood for cryo production and how to schedule the courier services such that the collection targets are met, and the total collection costs are minimized. A regional-level cryo collection problem imposes several challenges: i) if the blood collected is to be processed into cryo units, it has to be processed within eight hours after collection; ii) the collection quantities are uncertain due to no-shows, random walk-ins, and random yields in production; and iii) collection schedules need to be made in advance and may need to be dynamically adjusted depending on the realizations of uncertainties.

Historically, in the ARC’s southern region, cryo and noncryo site designations were determined at the end of the previous week. Cryo sites collected whole blood in cryo bags throughout the day, with all collected blood intended for cryo production. These sites typically required a midday pickup to meet the eight-hour processing window for blood units collected early in the day. In contrast, noncryo sites collected whole blood for noncryo production using regular blood bags, following a model termed the “nonsplit model,” where all or none of the blood collected at a site is designated for cryo collection.

In our project, an alternative collection model, referred to as the “split model,” was proposed and analyzed. In the split model, the collection window of each site is divided into two intervals, allowing cryo collection in both intervals or solely in the second interval. If only the second interval is designated for cryo collection, eliminating the need for cryo bags in the first interval, the mobile collection vehicle can transport the whole blood collected during the second interval to the production facility in time for cryo processing without incurring extra transportation costs.

To formally analyze the problem and optimize the collection schedules, we first formulated a large-scale Markov decision process (MDP). The model considered all collection sites and determined the sites for cryo collection dynamically over the week, given the day of the week, the type of blood collection, and the collection window. However, given the size of the problem, this MDP was computationally intractable. We analyzed this MDP model structurally, proved several structural properties, and developed a near-optimal solution algorithm. We also built a fast heuristic algorithm to solve the model and compare its performance with the MDP-based solution. To facilitate implementation, we further developed a decision support tool (DST) to systematize the selection of the collection sites, which is now used in practice in the entire southern US region.

Using historical real data from the ARC, we estimated the potential benefit of our proposed solution approach as a 70% reduction in total collection costs, leading to a roughly $100,000 cost reduction per regional center per year and a $4 million annual reduction in blood collection operations at the national level. The actual implementation of the DST in the ARC’s southern region resulted in an increase in the number of whole blood units that can be shipped back to the production facility and processed within eight hours after collection. During the fourth quarter of 2016, this facility processed about 1,000 more units of cryo per month (an increase of 20%) at a slightly lower collection cost, resulting in an approximately 40% reduction in the per-unit collection cost for cryo. Based on the successful implementation in the southern region, the ARC expanded the implementation of the DST, first to its St. Louis facility, and ultimately rolled it out to the entire nation.

Conclusions
In collaboration with the ARC, we tackled the challenge of optimizing blood collection schedules for perishable

Future research avenues might include simultaneous optimization of site scheduling and production decisions, as well as donor optimization strategies to maximize the efficiency and flexibility of blood component production.

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1 Original research articles based on this collaboration were published in Manufacturing & Service Operations Management (Ayer et al. 2019) and INFORMS Journal on Applied Analytics (Ayer et al. 2018).
products, a daily struggle for blood collection agencies. Our innovative approach introduced a collection model that divided each site into two intervals, accommodating different types of collections, departing from the conventional cryo or noncryo categorization.

To evaluate the value of this split model and optimize cryo collection schedules, we formulated the problem as a stochastic dynamic program, developing a near-optimal solution algorithm. Our numerical analysis, based on real data, demonstrated significant cost reductions compared to the previous approach. Post-implementation data confirmed our model’s effectiveness in increasing cryo collection quantity while keeping costs in check, benefitting the ARC’s production capacity expansion and cost management.

As a nonprofit organization reliant on blood donations, the ARC found these improvements substantial and implemented our proposed methods in multiple manufacturing facilities. This success underscores the potential impact of our collection model and solution approach for other blood collection organizations engaged in cryo unit production from whole blood.

Our innovative collection model, solution approach, and insights into cryo collection scheduling have broader implications for blood collection organizations involved in cryo unit production from whole blood. We anticipate that our research will encourage further exploration of various aspects of blood collection and procurement operations. Future research avenues might include simultaneous optimization of site scheduling and production decisions, as well as donor optimization strategies to maximize the efficiency and flexibility of blood component production. These endeavors hold the potential to enhance the overall performance and sustainability of blood supply chains.

References


An Interview with . . .

Kimberly Bryant, founder and CEO, the Black Innovation Lab, and founder, Black Girls Code

RON LATANISION (RML): Good afternoon, Kimberly. We’re thrilled you could join us for this conversation. We are very happy to talk with someone who is often described as a social innovator. I think that is a very nice label. Is that one you feel comfortable with?

KIMBERLY BRYANT: Absolutely. I think it appropriately describes how I have approached my work throughout my career to some extent but most certainly reflects my journey this past decade.

RML: Excellent. Let’s start at the beginning. Could you tell us a little bit about your history? I know that you received a degree in electrical engineering from Vanderbilt. What followed?

MS. BRYANT: Interestingly enough, I sort of stumbled into becoming an engineer and into the STEM field. I was placed into an accelerated math and science pipeline program back in my middle school and high school years in the public school system in Memphis, Tennessee. Then, when I got to my senior year, I was very focused on going into law. I was obsessed with the courtroom. I had grown up watching the original Perry Mason, and I wanted to be a lawyer, maybe a civil rights attorney or something of that sort since I was also very much concerned with social justice and civil rights issues. But because I had been in this accelerated program for math and science, it was my guidance counselor who suggested that I might explore engineering as a career field. And I ended up going to Vanderbilt University, getting a full academic scholarship from Junior Achievement. That began my engineering journey.

I was originally a civil engineering major, primarily because I wanted to explore a field of engineering that was most proximate to direct human impact. I thought that that would be civil engineering. I quickly found out that it was not a good fit for me and my interests. I decided to switch into electrical engineering, because the field was growing and there were many practical applications, especially in the area of technology. And that is what enticed me to switch my major.

After I left Vanderbilt, my focus in engineering was power engineering as opposed to the more technology or software side of electrical engineering. When I left, I went to work for Dupont as a project manager in a chemical manufacturing facility in New Johnsonville, Tennessee. I stayed there for about five years, and then I moved to North Carolina to work in a consumer packaging industrial manufacturing facility at Philip Morris. I was still on the project engineering or management side of the business but in a high-speed manufacturing facility, which was my first introduction to the consumer product manufacturing field. I was there for a little under five years, and then I transitioned into the pharmaceutical and biotech industry, working first at Merck, then at Pfizer. In 2006 I moved to the Bay Area to work at Genentech. There, I always worked to build a site technology group within the manufacturing and engineering team, which would eventually lead me back to my technology roots.
In my last two years at Genentech, I transitioned back into drawing on my technology skill set and doing some work in tech and the IT department before deciding to go right back to manufacturing. That was where my heart was. I found that this career trajectory pretty much primed me for doing the work that I would eventually do as a social innovator in the tech industry. My strong technology and engineering backbone was built in manufacturing and within a diverse and complex mix of manufacturing industries.

RML: The attraction to biotech was its manufacturing aspects and the manufacturing of their products, not so much the aspects related to biology. Is that an accurate description?

MS. BRYANT: I would say yes—to a degree. I would say unequivocally that out of all those different industries—chemical, consumer, manufacturing—the industry that I felt most connected to in my work was the pharmaceutical and biotech industry, especially in the years that I worked at Genentech because of the nature of the work that we were doing—and its alignment with my core values of utilizing technology and science to do good in the world.

When I worked in the tobacco manufacturing industry, I was most conflicted by the work that I was doing. Even though I was part of a world-class manufacturing and engineering team, my core values were in misalignment with the mission of the organization, and I was very conflicted. I learned a lot from that experience, but I also learned the importance and even the power of being deeply connected to the work from a mission perspective.

I found that my work within the pharmaceutical biotech industry most aligned with my core values—creating something that makes the world a better place, helps to cure disease, helps people to live longer lives, and so on. The ability to do that by utilizing my technology and engineering skills was just the icing on the cake. That helped me build and put things out into the world that helped people to live better.

KYLE GIPSON (KG): You mentioned how your experiences over the course of your career informed what you went on to do as a social entrepreneur. I am wondering if you would say a little more about what inspired you to become a leader in diversifying the tech industry, particularly when it comes to Black women. You are the founder and CEO of the Black Innovation Lab, which we’d love to talk more about later. You note on the Black Innovation Lab’s website that you became an “accidental social entrepreneur.” Can you elaborate on how it was kind of accidental that you moved into social entrepreneurship?

MS. BRYANT: I have said that a lot and, over the past couple of years, it has been clear to me that nothing in your life happens by accident. You are always where you are supposed to be at any given point in time. When I think back to my history, well before I knew what I wanted to do as far as my life and career path, I was always deeply connected to the community, social change, and social good.

When I was very young and in elementary school, I remember going to the library at my school and reading every single autobiography that was in the school library. Now, this was, of course, long ago—before digital. You had to go to the physical library and use the Dewey decimal system. My books of choice at that time were always the autobiographical novels and I loved all of them because I was just so intrigued by these leaders who would do these inspiring things in the world. Reading about their journeys felt like a profound exploration for me, and it provided insights into how they dedicated their lives to making the world a better place.

I was actively involved internally as a social change agent, as an inclusion and equity change agent.

Those stories influenced me much later as I began my career and as I participated in or was pulled into the leadership ranks of various employee resource groups within the larger corporate entities that I was a part of. This was in the early ’90s when DEI was not even used as a moniker. Certainly you would have chief diversity officers and such at companies. Maybe we would have an ERG for certain demographics of employees, but this was early on in the ERG movement, if you will. I remember being at DuPont and being very integral to the creation of the first Black employee network. It started small and then we expanded the network to all the chemical sites within the portfolios. It became a catalyst for creating more inclusion within the corporation. This was in the early nineties, when a lot of the deeply structured, strategic diversity programs weren’t even a thing.
I remember getting involved and seeing that there was a need to create these internal organizations to allow pathways for greater support and connectedness for marginalized employees internally and a need for leadership in this area. This was early in my career—I was in my early twenties and being active in that way. In every company that I worked at from that time forward, I was actively involved internally as a social change agent, as an inclusion and equity change agent. These were roles that I took on in addition to my day job. I was creating a lot of internal equity but also learning to move initiatives forward within the organizations I was part of. This knack for understanding how power moves within organizations would be crucial throughout my career. By the time I found myself on the path to creating Black Girls Code, I pulled from a lot of the knowledge and the skills that I had gained by doing this movement work internal to organizations and leveraged that into building this grassroots organization from the ground up.

I accidentally stumbled into this gap that wasn’t being filled and decided to create an organization to fill it.

But that wasn’t my intention. The accidental part refers to the fact that I didn’t create Black Girls Code because I wanted to create a nonprofit organization. That was not on my bingo card. I did not want to get into the nonprofit arena at all, but I saw a need to create change, to create some type of net to support girls who were interested in technology, like my daughter. It didn’t exist and I wanted it to exist in the world. I accidentally stumbled into this gap that wasn’t being filled and decided to create an organization to fill it.

RML: It’s clear from this conversation that you have a very deep social conscience, which I applaud. But I’m just curious, how did you transition away from your day job, for lack of a better word, when you left Genentech? Did you gradually transition to Black Girls Code, or did you just separate from Genentech and begin a totally new career?

MS. BRYANT: I left Genentech in 2010 when the company went through a corporate merger. I wanted to start my own company. I had an “entrepreneurial itch.” I was at the point where, and this is still true, I would never work for another corporation other than Genentech. And it was for a good reason: I thought that Genentech was the most ideal company from a diversity perspective that I had ever worked for during the twenty years of my career. I remember my first team at Genentech feeling like it was a United Nations—having someone from all these different communities and all these different demographics and backgrounds. And I said, this is what it should be. This is what every corporation should look like. I had many women leaders who were senior VPs and directors. Not that the organization was ideal. There certainly was work to be done from the diversity standpoint, but that was the most ideal environment I had been in during my corporate career. I loved it. I was like, I will never work in another corporation again. I know what I’m going to do next, but I’m not going somewhere else because this is the best that I’ve found.

But I did have an itch that I needed to scratch regarding entrepreneurship. I had been in the workforce and corporate America since 1990. And I was going to try my own hand in building something from the ground up. I wanted to create a startup company, one that was healthcare-focused, or wellness- and healthcare-focused, because that is where my heart was with the work I had been doing in pharma and biotech. But I didn’t have a specific idea of what I wanted to build. I just knew I wanted to build something of my own that I could run myself and that I wanted to make the world better through healthcare, wellness, et cetera.

RML: You did separate from Genentech as a fulltime employee to start Black Girls Code. Is that a correct assessment?

MS. BRYANT: Yes. But not to start Black Girls Code. My goal was to start a healthcare startup company. And, in the course of being on this journey, I was literally going to startup network events trying to find an idea. Now, as an investor, I always say, don’t do that. Don’t search for a solution to a problem that you don’t know exists. I would not give anybody that advice. But that was actually what I was doing. I knew I wanted to start something. I just didn’t know what that thing was, and I was searching for it.

I was still doing some consulting, and I did some work in the biotech area as a consultant. It’s like I was a fulltime employee after I left Genentech. And, in the course of trying to find the thing that I wanted to build,
I stumbled on this problem that needed to be solved around creating more inclusion in the tech industry, and that’s how Black Girls Code was born. I repeatedly found myself in rooms where there were not a lot of people who looked like me. And I was like, oh, this is a problem. Because I come from a corporate experience where I was surrounded by diversity and that diversity included many women in leadership roles making decisions, but here I’m not seeing any. Why does this industry look like this? I need to fix it. That’s how I went into the process of creating Black Girls Code. I would add that during this same time period my daughter Kai was also developing a blossoming interest in computer science by way of her gaming obsession. In many of the coding camps and experiences I was able to introduce her to as a middle school student, I was finding homogeneous environments that were eerily similar to what I was encountering within my networking experiences. It was a cycle I believed required drastic disruption.

RML: Do you still do any consulting with Genentech, any of the other biotech firms, or any of the other companies you've worked with?

MS. BRYANT: Yes. Interestingly enough, once I left Genentech and the biotech field and started Black Girls Code, I did not go back or spend any time in that industry as a consultant. Only now, since I have been starting this new path of becoming an investor, have I sort of circled back to biotech and the healthcare industry, from the standpoint of looking for opportunities to invest in the area. It’s the first time that I’ve been able to circle back to an opportunity to get involved in supporting the industry and helping the industry grow through new innovations and advancements primarily in the field of technology.

RML: That’s a fascinating journey. I’m interested in Black Girls Code and the evolution from essentially a one-stop shop to an organization with many different sites. How many different sites were you operating at?

MS. BRYANT: We had a peak of about fifteen chapters, mostly in the United States but one international chapter that was in Johannesburg, South Africa. But we started in the Bay Area. Actually, we started in San Francisco and then made our headquarters in Oakland, California. We built from the ground up and expanded. It was serendipity, really, that it became a chapter-based organization. That wasn’t our initial intent. Our initial intent was to build a San Francisco or Bay Area grassroots organization that was deeply embedded here in the community.

In 2012, we just sort of randomly decided: We are having so much success and seeing so much growth in the Bay Area. Why don’t we try to take this on the road and see if we get the same traction in other places? We were surprised to find that we did. We took that as an opportunity to expand our reach by having the organization create small pods or chapters in other cities and go from there.

RML: What was the experience like for the girls who were involved in these chapters? What were they being taught or what did they learn while they were there? Was it computer programming, or science?

I saw an opportunity to focus all of the knowledge and connections that I’d gained into creating this pipeline of founders, as opposed to just a pipeline of tech talent, and to create a pathway for more economic inclusion by opening up opportunities for founders from marginalized communities.

MS. BRYANT: Our goal initially was to train our girls to become full-stack engineers. We started with the basics, like teaching them web design. And when we first started the organization, we would do these build-a-website-in-a-day workshops. We would have the girls come in and teach them basic web development skills. At the end of the day, they would have this website that they built on their own. That was something that was always like a foundational piece of technology instruction we would do. Then we added a build-a-mobile-app-in-a-day workshop. Then we expanded from just web development to mobile app development. Then we would create a game in a day. Year by year, we would expand the pipeline and the basis of what we were teaching.

But our goal was that they would be able to have opportunities to learn it all. I think over the ten years that the
The organization evolved, we tried to touch on as many of the innovation advances as we could, bringing in workshops in augmented reality and virtual reality, bringing in some training about blockchain and cryptocurrency, bringing in training around cybersecurity, and then going into artificial intelligence in the latter years. And then we tried to make sure that the girls could see all the different potential possibilities within the tech industry and be able to find a place where they felt like home or that was of most interest to them. That was always our goal: to ensure that they could find somewhere that resonated with what they wanted to learn and what they wanted to do.

RML: Were these girls high school age?

MS. BRYANT: No. When we first started the organization, I really wanted to tap into where I saw the most need. I always say that the organization grew along with my daughter, because she was the prototype. The organization’s trajectory followed her in many ways. When I started Black Girls Code and my core team and I started to look at the research, we found that the gap where girls interested in computer science reaches a peak and then falls off a cliff is in middle school. We began with the intention that we would start with girls aged nine and ten-ish, and we would stay with them through high school. However, with the pilot program, we ended up with student participants who were much younger, like six or seven years old, because they were siblings. They came into the pilot program with their older siblings. We were happily surprised to find that the girls who were much younger were just as capable of, and often even more excited about, learning coding than the older girls.

We expanded it to be from six to eighteen years old. I think now it’s officially seven. Sometimes you get a six-year-old, but seven to eighteen years old is generally when students come into the program and stay with us.

One of the last things that I was able to initiate within the organization, back in 2020, was an alumni program. In 2020, my daughter was in college and about to graduate, and I was seeing that girls who were at that age needed something different. They needed more focus on career development. They needed more focus on career soft skills, mental health, et cetera. I created an alumni program. Now, the organization still does the formative programs from seven to eighteen, but there’s also an alumni program that helps them from the career development perspective.

RML: I was going to ask you about that because I think it would be interesting to track, in some fashion, where the girls who have been a part of the Black Girls Code program have landed. Have they used the experience successfully? What kind of experiences have they had?

MS. BRYANT: Absolutely. I transitioned away from the organization officially around this time last year, in August of 2022, and started to really focus on working directly with other founders and innovators, which evolved into...
the vision for my new venture, the Black Innovation Lab. But, thankfully, the organization has continued to push forward. It’s still in operation. It has an office and a team in New York City primarily, but it still has a presence here in the Bay Area, and they still do, for now, run the chapter programs. But the organization has mostly survived, which is something that was my biggest concern, because I do see that there is so much work that needs to be done in the tech industry, especially in regards to creating pathways for and supporting Black and brown girls in the STEM fields.

RML: I’m so delighted to hear what you just said because I think it’s such a beautiful concept. I didn’t know what the upshot of all of the discussion was in 2021, but I’m happy to hear this. I think it would be a tragedy to lose all that wonderful activity.

MS. BRYANT: I think, and I firmly believe, that the strongest legacy of the organization lives in the girls and the alumni who have been part of the program. My daughter graduated from college last year and is now working as a product manager at Microsoft. My goal initially was to start this organization to create a support system for my daughter. But little did I know I would gain even more daughters in the course of doing this work. That’s exactly what I did. But there are still girls who are coming into the program and discovering it now. Black Girls Code still needs to exist in the world.

I only have one biological daughter, but my company, Black Girls Code, was also my baby. The fact that it can still survive and do this super important work in the world is something that makes my soul happy and at ease.

RML: I think you and I share a sense that the people whom we involve ourselves with become something of an extended family. I taught at MIT for thirty years. And the students who have been through my lab are like my children. I care about them. I try to help them. I love to watch them grow. One of my students is the dean of engineering at Tel Aviv University. I’ve been very concerned about him, given the recent course of events. But there have been deans and corporate CEOs and, for me, I sense the same thing in your comments: Watching all these young people grow is part of a legacy that is so wonderful. I applaud what you’ve done with this. I think it’s wonderful.

Is the Black Innovation Lab a follow-on to Black Girls Code? How is it distinct from Black Girls Code?

MS. BRYANT: I would not consider it a follow-on, but it is an extension of the work. I think one of the things that I was so focused on when I led Black Girls Code is creating an opportunity for other founders and innovators like myself in the nonprofit and for-profit realm, so that they would have support to build their dreams and to learn the things that they may not know. I started to talk a lot to founders on both the nonprofit side and the for-profit side, and I loved it. I found that I got so much energy from that and sharing my experiences, my challenges, my ups and downs, and my advice. But I wanted to do more than just give pieces of advice. I wanted to write a check for many of them who were also challenged with being able to find the support they needed to build their dreams. I resonated with that, so fiercely, based on my experiences trying to build Black Girls Code.

So, this concept of creating a Black Innovation Lab became a very strong vision for what I wanted to do next. I often brought up this concept of creating a Black Innovation Lab years ago, before I ever left Black Girls Code. I wanted to create an innovation lab in our New York office space, and then I did. We built an office.
There was a mini lab in there, but it wasn’t like the vision of the Black Innovation Lab that I have now.

It came up again in 2020, when we were doing our long-term strategic planning. I was like, this is great, but what about this innovation lab? The consultants were like, that is a great idea, but does it have to be here at Black Girls Code? Maybe you could do that separately. And I was like, do you think I can? They were like, yes.

When I did transition from the organization, I certainly wasn’t initially thinking this, but I started to have these conversations. That’s when I evolved. I thought: Now is the time to build this innovation lab. It doesn’t have to be a part of Black Girls Code and it actually is an extension of that work, but in a different way, and focusing on, not just creating this pipeline of coders, but creating a pipeline of innovators who are building the next generation of technology companies. I can go back to my hometown, Memphis, Tennessee, and seed a tech movement around ownership in the realm of technology in a way that I haven’t even thought of before. That’s the vision and the goal of the Black Innovation Lab. Memphis has a significant racial equity gap. Memphis is a “majority minority” city with over 63% of its population identifying as Black or African American. Unfortunately, Black residents in Memphis experience higher levels of poverty, lower rates of homeownership, and lower levels of access to capital than white residents. This disparity extends to the city’s entrepreneurial ecosystem, with Black-owned businesses making up only a small percentage of the city’s startup scene. My goal is to address these disparities by seeding a startup district, anchored by the Black Innovation Lab, and investing in companies founded by entrepreneurs from socially and economically disadvantaged communities in Memphis and throughout the region. By creating a robust program to accelerate these companies, we can provide a significant return on investment while also addressing the racial equity gap.

KG: In what ways is the Black Innovation Lab an extension of what you’ve been working towards over the course of your career, and in what ways is it a departure?

MS. BRYANT: One of the things that I felt so strongly about as I was building Black Girls Code was that, at some point, it was part of our mission statement that we were going to teach these technology skills to girls from underrepresented communities with a focus on entrepreneurial concepts. When we put that vision in place and in action within the organization, there was always that underlying tone of entrepreneurship, but it really evidenced itself and blossomed from the girls themselves. As we did this research with our students from the time when we began in 2012 and throughout 2020, ’21, and ’22, we would find that many of the girls and students who were coming to our program were building this strong entrepreneurial mindset. It wasn’t necessarily intentionally in the curriculum, but these were the types of mindsets and processes that they were organically developing, and that was great.

As I left the organization, I felt very strongly that, with the changes in the tech industry and certainly some massive layoffs that plagued the industry over the last couple of years and even my own experience as a founder of a nonprofit organization, we needed to do more than just feed these girls into a tech pipeline. They may survive it, but maybe they won’t. Maybe these companies won’t value them. We needed them to be the makers and the creators. I saw an opportunity to focus all of the knowledge and connections that I’d gained into creating this pipeline of founders, as opposed to just a pipeline of tech talent, and to create a pathway for more economic inclu-
sion by opening up opportunities for founders from marginalized communities to achieve success in science.

This builds on some of the work that I have done from a pipeline perspective but in a different way, focusing on how to recreate more economic equity here in the United States, and even abroad, by creating opportunities for founders of color to rise and be able to scale into a company.

KG: That’s wonderful. I just want to zoom out a little bit. You’ve been a trailblazer in terms of diversifying the tech industry for such a long time and you have a long view of what has happened in the conversation around it. I’m wondering where, if anywhere, you are seeing progress when it comes to diversifying the tech industry and where you’re still noticing blockages when it comes to including more Black women and other women of color in the tech industry.

MS. BRYANT: I think that, unfortunately, when I started Black Girls Code in 2011 and 2012, there wasn’t a lot of focus on diversity and inclusion in the industry and there was even perhaps a bit of denial that we had an issue. That started to change around 2013 when companies such as Google and Facebook were required to release their diversity and inclusion numbers. The elephant in the room became very clear: We actually did have a problem in the industry when it came to diversity. At that moment, that was a threshold change for Black Girls Code.

Those diversity reports were released and made available to the public in 2013 by a lot of the efforts of technologists like Tracy Chou. It was a night-and-day difference from before 2013 to after. Before 2013, we were almost begging people to support us and give us a donation. It was a challenging time. And that changed almost overnight when those diversity numbers were made public. People started to come to us saying, “We have some diversity challenges. Your program could help us.” Not that all my problems went away in that moment. They did not. It was still challenging, but it wasn’t as challenging as it was before. That was a marked change in how we were able to do our work.

Between 2013 and the next seven years or so, things slowly improved in terms of opportunities for people of color to work for a lot of these tech companies. I saw lots of improvement from the standpoint of women being able to go into these tech companies and also being able to rise a bit through the leadership ring. I did not see as much movement into the leadership ring for some other marginalized communities. Women did increase their presence within tech companies, and the needle moved a little bit.

Things changed in 2020, the year of COVID and the strong racial reckoning. I like to call the summer of 2020 the summer of resistance. I think what that turning point meant is that organizations like Black Girls Code received an overwhelming amount of commitment and support financially and otherwise from all sorts of everyday people as well as large corporations and such. But it didn’t move the needle. Like I said, dollars were poured into these organizations and commitments were made. But when you look at the numbers now, in 2023, the numbers in terms of diversity and inclusion in many of these companies, especially for African Americans and some other marginalized Latino communities, are not good. There are fewer Black women in the tech industry now. The numbers have actually decreased over the last ten years rather than increased. Women have done fairly better, but it’s certainly not at the equitable place where it should be.

That tells me that there’s still a lot of work to be done. I’m still undecided about what is at the root of the lack of progress after 2020. I’ve been asking this question a bit in my interactions with folks who are still in industry: Is there still a commitment to diversity in these companies? I often get told there is. But I think perhaps what we are
seeing is maybe a bit of disillusionment on the side of folks who would perhaps be looking to join companies. When it comes to trying to get into tech, people are tending to opt out as opposed to opting in.

That brings us to a place where there’s also opportunity in this, right? I think there’s an opportunity to create avenues for people to become the creators of the jobs we have so often sought to fill through various pipeline movements. This is certainly not an invitation for everyone to become entrepreneurs—it is certainly not an easy path to pursue. But I think we have an opportunity to infuse the innovation economy with new energy, new perspectives, and new ideas by developing space for more innovators to build, and there is no better time than now.

RML: What are your goals for the next five or ten years?

MS. BRYANT: I have been on this journey of learning this new industry, from venture capital investment to building the Black Innovation Lab, and learning about how to build an accelerator. I’m finding myself in rooms where there is a lot of talk about what’s the next iteration of innovation.

I think, expectedly, everybody is talking about artificial intelligence right now, but there are other tremendous opportunities in space and innovation for space. We will probably be on Mars a lot quicker than many people realize, and the industry has a lot of growth and opportunity in that and innovation that will go into those colonies and space exploration. It’s not just about Elon Musk or what Amazon is doing, or Bezos, or Blue Origin. There’s going to be a lot of innovation required for space exploration, but also in the work that is done off-planet that supports things that we’re doing here. There’s a lot of opportunity around sustainability and, of course, incredible advancements in healthcare and other areas that impact our rapidly aging society.

I believe we’re on the cusp of a new golden era of innovation, marking the onset of what I term the fourth industrial revolution. It’s crucial to ensure that the multitude of advancements unfolding over the next century that profoundly impact humanity are fueled by a rich diversity of thoughts and ideas. This diversity will be the driving force behind innovations that not only create opportunities but also uplift and support all of humanity. That is my goal.

The focus of my current efforts with the Black Innovation Lab is squarely on addressing this issue—creating a significant impact within a confined space where only a select few emerge as creators, founders, and builders. My goal is to rupture this exclusive bubble. I want to establish a robust pipeline of builders who, like myself, represent diversity and can contribute positively to the betterment of the world, using technology not as a solution but as a lever.

RML: That’s a wonderful vision of the future and goal from the perspective of all of the things you are doing, Kimberly. You’ve just been a wonderful addition to our interview series. I want to thank you for that.

MS. BRYANT: Thank you. And thank you for having me.

RML: You’re such an inspiration. Your commitment to all this is so palpable. I don’t think anything happens unless people are really committed. I can tell that you are fully committed. That’s a wonderful recognition, I think, to feel the commitment just in the way you speak about this. Thank you.
NAE News and Notes

NAE Members Awarded National Medals of Science and of Technology and Innovation

The 2022 National Medal of Science Laureates and 2022 National Medal of Technology and Innovation Laureates received their medals from President Biden on October 24, 2023, at a White House ceremony. This was the first time in seven years that the nation’s highest honors for achievement and leadership in advancing the fields of science and technology were so honored. Eight recipients were NAE members.

The National Medal of Science recognizes individuals who have made outstanding contributions to science and engineering.

Subra Suresh (NAS/NAM), president, Global Learning Council, and Vannevar Bush, professor emeritus, Massachusetts Institute of Technology, for “pioneering research across engineering, physical sciences, and life sciences. A transformative educator, he has advanced the study of material science and its application to other disciplines. His commitment to research and collaboration across borders has demonstrated how science can forge understanding and cooperation among people and nations.”

Sheldon Weinbaum (NAS/NAM), CUNY distinguished professor of biomedical engineering (emeritus), the City College of the City University of New York, for “pathbreaking research in biomechanics. His models have driven innovation in physiology, bone biology, and blood flow, increasing our understanding of cardiovascular disease and leading to lifesaving treatments. His exceptional teaching and mentorship underscore his lifelong advocacy for diversity and inclusion, tapping into the full talents of [the] nation.”

The National Medal of Technology and Innovation recognizes those who have made lasting contributions to America’s competitiveness and quality of life and helped strengthen the nation’s technological workforce. Of the eight medals awarded, seven were given to NAE members.

John M. Cioffi, Hitachi American Endowed Professor Emeritus (recalled), Stanford University, for “advancements that helped bring high-speed Internet to the world. The digital subscriber line that he helped invent ignited the growth of the digital age, vastly increasing people’s access to information, reshaping the global economy, and transforming how we work, communicate, and find community.”

Ashok J. Gadgil, professor area deputy for science and technology, University of California, Berkeley, for “providing life-sustaining resources to communities around the world. His innovative, inexpensive technologies help meet profound needs, from..."
drinking water to fuel-efficient cook-stoves. His work is inspired by a belief in the dignity of all people and in our power to solve the great challenges of our time.”

Jeong H. Kim, chairman, Kiswe Mobile Inc., for “advances in engineering and technology that transformed how we communicate. His work on broadband optical systems, data communications, and wireless technologies have made communication faster and clearer, including improvements in battlefield communications that strengthen our national security. He exemplifies the power of American entrepreneurship and innovation.”

Neil G. Siegel, retired sector vice president and chief technology officer, Northrop Grumman Information Systems, for “technology that bolstered our nation’s security, economy, and connectivity. His creation of the ‘digital battlefield’ represented a new approach to combat operations, integrating secure communications and precise, real-time data to minimize U.S. casualties and protect allies and civilians. Today, technologies he invented are found in smartphones everywhere.”

James Fujimoto (NAS), Elihu Thomson Professor of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, and David Huang, professor, Ophthalmology & Biomedical Engineering, Oregon Health and Science University, shared the award with Eric Swanson, affiliate, Research Laboratory of Electronics, MIT, for “enhancing human vision. Their invention of optical coherence tomography transformed ophthalmology by providing a detailed image of the retina for the first time. Their work is now the standard of care for the detection and treatment of eye disease, giving millions a new chance to see the world.”

You can read President Biden’s remarks at https://www.whitehouse.gov/briefing-room/speeches-remarks/2023/10/24/.
Rakesh Agrawal, Winthrop E. Stone Distinguished Professor, Purdue University, was the James Y. Oldshue Lecturer on June 6 at the 11th World Congress of Chemical Engineering in Buenos Aires. This lecture was established in 2008 in memory of James Y. Oldshue (NAE 1980) by the American Institute of Chemical Engineers and the Interamerican Confederation of Chemical Engineering (CIIQ/IACChE). The title of Dr. Agrawal's lecture was “Chemical Engineering for a Sustainable World.”

The annual Research!America Advocacy Awards recognizes individuals and organizations whose leadership efforts have advanced the nation’s commitment to medical, health, and scientific research. Robert W. Conn, president and CEO emeritus of The Kavli Foundation, will receive the 2024 Gordon and Llura Gund Leadership Award. The award recognizes individuals who have made a significant contribution to increasing the level of advocacy for medical and health research at the local, state, or national level. He has been a leader in science philanthropy, a champion of basic science and technology research, and co-founded the Science Philanthropy Alliance. Norman R. Augustine, retired chairman and CEO of Lockheed Martin, will receive the 2024 Herbert Pardes Family Award for National Leadership in Advocacy for Research, which recognizes individuals who, throughout their careers, have demonstrated distinguished leadership and sustained commitment to public engagement and advocacy for research. Mr. Augustine is a tireless advocate for research in the public and private sectors.

Rodney C. Ewing, Frank Stanton Professor in Nuclear Security, codirector of the Center for International Security and Cooperation, and professor, Department of Earth & Planetary Sciences, Stanford University, is the 2023 recipient of the William B. Heroy Jr. Award for Distinguished Service to AGI (American Geosciences Institute). The award is given in recognition of exceptional and beneficial long-term service to the AGI.

James G. Fujimoto, Elihu Thomson Professor of Electrical Engineering, MIT, and David Huang, associate director and director of research of the Casey Eye Institute, Peterson Professor of Ophthalmology, professor of bioengineering, and Wold Family Chair in Ophthalmic Imaging, Oregon Health & Science University, are recipients of the 2023 Lasker-DeBakey Clinical Medical Research Award, the most distinguished biomedical research award in the United States. They share the award with Eric A. Swanson of MIT. The three are coinventors of optical coherence tomography (OCT). The award, given by the Albert and Mary Lasker Foundation, recognizes leaders who have made major advances in the understanding, diagnosis, treatment, cure, and prevention of human disease. OCT routinely helps prevent blindness and is increasingly used to diagnose and treat conditions of the heart, brain, skin, and more.

Elisabeth Louise Marie Guazzelli, senior researcher, Matière et Systèmes Complexes, CNRS-University of Paris VI, has received the Fluid Dynamics Prize of the American Physical Society. She earned the award “for ground-breaking experiments on fluid-particle systems; for advances in the unification of the rheological description of dry granular media and dense ‘wet’ suspensions; for guidance of theory through focused and creative experiments; and for leadership in the fluid mechanics community.”

Jerome F. Hajjar, CDM Smith Professor and chair, Department of Civil and Environmental Engineering, Northeastern University, will receive the 2024 SSRC Lynn S. Beedle Award, established to honor the late Lynn S. Beedle (NAE 1972). This lifetime achievement award from the Structural Stability Research Council is given him in recognition of world-class research in the field of structural stability.

Kazunori Kataoka, director general of the Innovation Center of NanoMedicine, University of Tokyo, has been named a Citation Laureate 2023 by Clarivate, a global provider of information services. This prize is awarded to researchers who have an extremely high citation record and whose research is deemed to have such an impact on society that they are worthy of the Nobel Prize.

Cato T. Laurencin, University Professor and chief executive officer, the Cato T. Laurencin Institute for Regenerative Engineering, University of Connecticut, has been named the 2023 Inventor of the Year by the Intellectual Property Owners Education Foundation for his groundbreaking work in regenerative engineering. Dr. Laurencin will be presented the award at the 2023 IPOEF Awards Celebration on December 6, 2023, in Washington, DC.

Fei-Fei Li, Sequoia Capital Professor Operations, Information,
Stanford University, will receive the **Woodrow Wilson Award** from Princeton University on February 24, 2024. The University bestows the award annually upon an undergraduate alumna or alumnus whose career embodies the call to duty in Wilson’s 1896 speech, “Princeton in the Nation’s Service.”

**Asad M. Madni**, independent consultant, retired president, and chief operating officer and CTO, BEI Technologies Inc., has been awarded the **John Fritz Medal** by SME, widely considered the highest award in the engineering profession. His citation reads, “for seminal and pioneering contributions to the development and commercialization of innovative sensing and systems technologies, distinguished research leadership, and service to the nation.” The medal will be awarded to Dr. Madni at the MINEXCHANGE 2024 SME Annual Conference & Expo in Phoenix, Arizona, on Wednesday, February 28.

**Lindsey C. Marr**, Charles P. Lunsford Professor, Virginia Polytechnic Institute and State University, has been named a **2023 MacArthur Fellow**. Selection criteria for the award are exceptional creativity, promise for important future advances based on a track record of significant accomplishments, and potential for the fellowship to facilitate subsequent creative work. Dr. Marr hopes to use the fellowship to support research and projects that would be hard to fund through traditional channels.

The **Frontier Design Prize** announced the winners of its inaugural edition during the opening ceremony of the World Design Cities Conference held in Shanghai in September 2022. Three prize categories are set up to reward and recognize outstanding personalities and works of design that have made a pioneering contribution to the design field with far-reaching international influence. NAE member **Donald A. Norman**, distinguished professor and founding director emeritus, the Design Lab, University of California, San Diego, won the **Distinguished Contribution** prize for pioneering contributions to the fields of cognitive science, human factors engineering, and interaction design.

The Institution of Engineering and Technology announced its 2023 IET Achievement Awards winners. **Arogyaswami J. Paulraj**, professor emeritus, Stanford University, has won the **Faraday Medal** from IET. Professor Paulraj received the award for the invention, advancement, and commercialisation of MIMO (Multiple-antenna Input, Multiple-antenna Output) wireless technology. **James J. Collins**, Henry Termeer Professor of Medical Engineering & Science, Massachusetts Institute of Technology, received the **IET Achievement Medal in Biomedical and Healthcare** for his pioneering work on synthetic gene circuits and programmable cells that helped to establish the field of synthetic biology, enabling engineers to program biological systems with novel functions for a variety of applications.

**J. Marshall Shepherd** (NAS) was recently named the recipient of the prestigious **2023 Environmental Achievement Award** presented annually by the Environmental Law Institute to individuals or organizations that have made notable contributions to environmental protection, conservation, and sustainability. Dr. Shepherd’s longstanding record of exceptional scientific research, thought leadership, and public education on atmospheric sciences was referenced in the presentation comments.

**Andrew M. Weiner**, Scifres Distinguished Professor, School of Electrical and Computer Engineering, Purdue University, has been awarded the **2023 Charles Hard Townes Medal** by Optica (formerly OSA). The medal is presented for outstanding experimental or theoretical work, discovery or invention in the field of quantum electronics. Dr. Weiner is recognized for groundbreaking work bringing optical frequency combs to the quantum world and developing innovative applications spanning several fields, including coherent control, generation and line-by-line manipulation of frequency combs, and ultrabroadband radio-frequency photonics.

Five NAE members have been elected **International Fellows of the Royal Academy of Engineering**. **Nadine Aubry**, professor, School of Engineering, Tufts University, and the George and Virginia Bugliarello NAE International Secretary, is recognized for outstanding contributions to fluid mechanics and leadership in the global engineering community. **Richard Miller**, emeritus president, Olin College of Engineering, and founding chair, Coalition for Transformational Education, is recognized for developing a higher education institution renowned for its excellence in engineering education that has had profound transformational global impact. **Viola Vogel**, professor, Department of Health Sciences and Technology, ETH Zürich, Switzerland, is recognized for discovering the first high-resolution structural mechanisms about how nature exploits proteins and translating them towards medical applications. **Vikram Deshpande**,
professor of materials engineering, University of Cambridge, is recognized for seminal contributions to the mechanics of engineering materials. Wolfgang Marquardt, emeritus chairman of the Board of Directors, Forschungszentrum Jülich GmbH, is recognized for seminal contributions across the entire spectrum, from product and process design to operations and control, as well as to the underpinning methodologies for process modelling, model-based experimental analysis, and numerical methods.

The Hagler Institute for Advanced Study at Texas A&M University will induct the Class of 2023–24 Hager Fellows during its annual gala in March. Included in the new class of fourteen were NAE members George Georgiou, professor, University of Texas at Austin; Kyle J. Myers, principal, Puente Solutions LLC; Eleftherios T. Papoutsakis, Unidel Eugene Dupont Chair of Chemical Engineering, University of Delaware; Radia J. Perlman, fellow, EMC Corporation; and Soroosh Sorooshian, distinguished professor and director, Center for Hydro meteorology and Remote Sensing, University of California, Irvine. In addition, the institute announced two Hagler Distinguished Lecturers for 2023–24: Julio M. Ottino, dean, R.R. McCormick Institute Professor and Walter P. Murphy Professor of Chemical & Biological Engineering, Northwestern University, Evanston, and Mark D. Zoback, Benjamin M. Page Professor, Geophysics, Stanford University.

On October 9 the National Academy of Medicine announced the election of new members during its Annual Meeting. Three NAE members were elected to NAM membership. Regina Barzilay, distinguished professor for AI and health, MIT, for “the development of machine learning tools that have been transformational for breast cancer screening and risk assessment, and for the development of molecular design tools broadly utilized for drug discovery.” Jennifer L. West, Fitzpatrick Family University Professor and dean, School of Engineering and Applied Science, University of Virginia, for “the invention, development and translation of novel biomaterials including bioactive, photopolymerizable hydrogels and theranostic nanoparticles.” Jens Nielsen, CEO and professor, BioInnovation Institute, Copenhagen, for “developing a systems biology approach for studying human metabolism with the objective to identify novel biomarkers and drug targets for metabolic diseases like type-2-diabetes, liver diseases and cancer. Several of his findings have been translated for use in the clinic for improved diagnosis.” Dr. Nielsen now has the added honor of being a member of all three Academies.

### 2023 NAE Annual Meeting Highlights Sustainability

The National Academy of Engineering welcomed members and the public to its 2023 Annual Meeting, “Engineering the Future for Sustainability,” held October 1–2 in Washington, DC.

“The engineering profession’s commitment to sustainability—and the importance of it—has never been stronger,” said NAE President John L. Anderson. “Innovating and rebuilding with sustainability in mind requires expertise and creativity relevant to all disciplines within engineering.”

According to Anderson, “Choosing sustainability as the topic of the 2023 NAE Annual Meeting aimed to facilitate collaboration among all engineering and science disciplines, including the social sciences, and exchange diverse ideas from leading topic experts about new developments in their fields.”

The event kicked off with a standing-room only 2023 Class of NAE Members Induction Ceremony led by Anderson, NAE Chair Donald C. Winter, and NAE Executive Officer Alton D. Romig, Jr.

“While the NAE selects its new members based on an exhaustive search and evaluation process, it is much more than just an honorific society,” Winter said. “Our role as an advisor to the nation on technical matters has been a core responsibility.”

This sentiment was echoed by Romig, who said, “Today, we are celebrating the marvelous contributions that the engineers in this year’s class have made in research, innovation, manufacturing, education, the creation of novel technologies, and in designing solutions to real-world problems. Engineering improves the human condition, and that is the message we are consistently trying to convey to the public young and old.”

The pursuit of improving the human condition is one of many reasons that interest in artificial intelligence (AI) has rapidly increased and why industry leaders are looking at how AI can enhance our understanding of human behavior.
Leading a discussion on “Engineering Ecosystems with AI,” Alex “Sandy” Pentland examined how tools like AI and large language models could help integrate human behavior into predictive models to improve our responses to vexing societal challenges such as climate change, pandemics, and income inequality. Pentland, the director of the MIT Connection Science Research Initiative and creator and previous director of the MIT Media Lab and the Media Lab Asia in India, is a pioneer in harnessing network science to understand and change real-world human behaviors.

“The reason you might want to pay attention, other than intellectual interest, is that the new federal infrastructure bill includes social structure in the definition of infrastructure,” Pentland said. “In other words, they’re saying engineering social structure is now part of engineering. That might be a little controversial, but the non-controversial way to put it is when you build a highway, you advantage certain people and disadvantage other people. When you come up with any sort of policy or infrastructure, it has differential effects, some of which are not immediately obvious, and it’s saying you should think about that. Now, why did they put that on that bill? Because of the failures that we’ve experienced from not accounting for
human social structure and human behavior."

Pentland went on to discuss how AI, if utilized correctly, could help bridge gaps in policy. "A natural way for AI to be used is to help people understand more opportunities, more facts, and what other people do as a common-sense engine to help upskill people."

While AI is heralded for its ability to help predict human behavior and accelerate solutions to societal challenges, equally important are conversations around sustainability, the topic of the plenary session, "Sustainability: The Defining Challenge and Opportunity of the 21st Century," led by Arun Majumdar, Jay Precourt Professor of Mechanical Engineering & Energy Science and Engineering at Stanford University. That plenary presented a comprehensive overview of our global sustainability problem and elaborated on the urgency of the matter.

"I've been using an indigenous quote, which my staff decided to paint on my office wall. It's about how we look at the future," Majumdar said. "'We do not inherit this earth from our ancestors. We are borrowing it from our children.' That gives a perspective of what we do in the next 10 to 20 years is going to be extremely important with the world we leave behind for children and grandchildren. This needs to be done, in the words of Martin Luther King, 'with a fierce urgency of now.'"

With the goal of using interdisciplinary collaboration to tackle climate issues, the "Forum on Engineering the Future for Sustainability" featured a panel of environmental and sustainability experts. Moderator Deanne Bell, founder and CEO of Future Engineers, guided the conversation as each expert delved into their area of expertise.

"Much of the sustainability to date has also been focused on decarbonization efforts, and measuring progress in some ways is easier for climate mitigation. It's avoided, reduced, or removed greenhouse gases," said Sarah Kapnick, chief scientist of the National Oceanic and Atmospheric Administration. "Measuring progress, however, towards climate resilience requires much different metrics. It requires flood-resilient buildings, extreme-weather-resilient grids [among other things] being implemented. There's a number of things that need to be done to build out our ability to measure that going forward."

Progress in sustainability, be it mitigation or resilience, calls for a global effort to expedite the process. According to David Allen, Norbert Dittrich-Welch Chair in Chemical Engineering, director of the Center for Energy and Environmental Resources, and co-director of the Energy Emissions Modeling and Data Lab at the University of Texas at Austin, "Right now, the US Department of Energy is leading the effort to bring in an international consortium of countries of both importers of natural gas and exporters of natural gas to agree to a global playing field. There are immense technical challenges on this, but the goal is big, and we can engineer these systems for measuring, reporting, and then independently verifying the sustainability features of our products. These are on the verge of development but need guidance from organizations like the National Academies and need the work of engineers to put all these systems together."

As global efforts increase, Erkan Erdem, partner and the National Leader of Economic Services prac-
KPMG LLP, told meeting attendees that it is important to include a more rigorous and required standard of sustainability reporting. "In terms of the current state of sustainability... what we see in a survey of major companies in late 2020 is that Global Reporting Initiative (GRI) is becoming the choice of standards that companies rely on," Erdem said. “It’s a little ahead of the United States in terms of what percent of the companies report on environmental, social, and governance (ESG)-related metrics in South America, Asia, as well as Europe. Many of these include a long list of measures.”

According to NAE Vice President Wesley Harris, “Sustainability is perhaps our greatest global challenge, but as Arun pointed out, it also presents our greatest opportunity. Defining challenges and seizing opportunities enable engineers to accomplish great feats. These are the very attributes that are the hallmarks of innovation. And the ability to accomplish great feats is what makes some engineers stand above others.”

As host of the 2023 Award Ceremony: Celebrating Trailblazers of Engineering Innovation, Harris noted that, “We are here to celebrate the trailblazers in engineering innovation. Engineers who saw a challenge, seized an opportunity, and accomplished great feats. And they did this again and again throughout their careers.” Engineers honored at the 2023 NAE Annual Meeting were:

- **Robert W. Conn**, Walter Zable Distinguished Professor and dean of engineering (emeritus) at the University of California, San Diego, received the Simon Ramo Founders Award “for shaping national science and technology policy through leadership in academia, business, and philanthropy and for seminal contributions to fusion engineering.” The Simon Ramo Founders Award honors an outstanding NAE member or international member who has upheld the ideals and principles of the NAE through professional, educational, and personal achievements.

- **David Tennenhouse**, senior advisor in the National Science Foundation’s Directorate for Technology, Innovation, and Partnerships (TIP), received the Arthur M. Bueche Award “for the conception, implementation, and stewardship of information technology R&D involving unique partnerships among academia, industry, and government.” The Arthur M. Bueche Award recognizes an engineer who has been actively involved in determining US science and technology policy, promoting technological development, and contributing to the enhancement of relations between industry, government, and academia.

Also honored was **Nadine N. Aubry**, professor at Tufts University, who was installed as the George and Virginia Bugliarello International Secretary.

The meeting also included a Celebration of Life for Wm. A. Wulf, NAE president from 1996–2007. Colleagues, friends, students, and family members of the late NAE president spoke of how he inspired and enhanced their lives and the lives of everyone around him. Bill’s legacy will live on through the Wm. A. Wulf Initiative for Engineering Excellence Endowment. Led by several of Bill’s and his wife Anita John’s friends from NAE Section 5—Susan Graham, Ed Lazowska, and Bob Sproull—an effort was made to honor Bill’s memory by doubling the original Wulf Endowment to sustain and grow the programs that Bill championed and to further strengthen the NAE programs aligned with its mission. As of November 8, 2023, nearly $3.6 million of the $5 million goal has been raised. The NAE is grateful to all those who have given and would like to encourage all members to support this effort and Bill’s legacy.

Videos and presentations from the 2023 NAE Annual Meeting are available for viewing on the NAE Annual Meeting webpages and on the NAE YouTube channel; links to both are accessible on the NAE homepage at www.nae.edu.
Good morning. It is my great honor and privilege, as the NAE chair, to welcome all of you to the National Academy of Engineering Annual Meeting and the induction of the class of 2023.

For many of the new members this is your first introduction to the academy. Election to the NAE is a high honor and I trust that you will take great satisfaction in being so recognized by your peers. I expect that your families also take great pride in this accomplishment. But while the NAE selects its new members based on an exhaustive search and evaluation process, it is much more than just an honorific society.

The National Academy of Sciences was established in 1863 by act of Congress. Its charter directs the academy, “whenever called upon by any department or agency of the government, to investigate, examine, experiment, and report upon any subject of science or art.” The National Academy of Engineering was founded in 1964 under that charter. I will let John Anderson describe the operating structure of the National Academies of Sciences, Engineering, and Medicine, but I will note that our role as an advisor to the nation on technical matters has been a core responsibility for over 150 years.

During this period, the Academies have been relied upon to provide independent, objective, and nonpartisan advice with the highest standards of scientific and technical quality and integrity. To do so, the Academies call on the nation’s preeminent experts in science, engineering, and medicine. In this process, the often critically needed engineering perspective has been, and will continue to be, a major demand function for the NAE.

An aging transportation infrastructure, climate change, the limitations of our electric grid, the emergence of generative AI, and the application of autonomy from automobiles to aircraft, just for a few examples, all pose great policy and appropriation challenges for our Congress and the executive branch. And yet these are matters that require a significant level of technical understanding to address properly.

Perhaps not surprisingly, our Congress has very few members with the background needed to provide a knowledgeable technical perspective. The clerk of the House of Representatives recently released a list of the eighteen members in the 118th Congress that are deemed to be engineers. By the way, that is 18 out of 435 members or roughly 4%. Unfortunately, the number of members identified by the clerk as engineers that can be expected to be current and expert in their field is quite a bit smaller. With a few notable exceptions, most had very limited experience as engineering practitioners before they entered politics.

While the Senate has not issued a list of their engineers, an examination of the Senate’s current membership suggests a similar situation, with just a few members having a basic engineering education but with limited experience as practitioners.

The net of this situation is that our Congress is dependent upon the advice that they receive in reports and in testimony before the various committees. Unfortunately, while there are many individuals, organizations, and corporations willing to offer their opinions, such advice is often tainted by the political and financial implications of the legislation under consideration. What is badly needed is expert, apolitical advice, free of any factual or perceived conflicts of interest.

The National Academies is one of a very few organizations that are able to provide such advice. We can bring to bear the engineering leadership of the United States, and we have the policies and procedures needed to ensure that our advice is free from political or financial taint. Our reputation for doing so is one of our most important assets and must be protected vigorously; a challenge in these fractious times, particularly as we approach next year’s federal election. Our publicly stated opinions and positions need to be limited to those based on technical assessments, in accordance with our long-established processes.

To accomplish these objectives, we need more members to participate on the many National Research Council committees, boards, and
The BRIDGE

The BRIDGE

NAE programs. For those of you who have served, I would like to thank you and ask that you continue to do so, perhaps at even greater levels of involvement. For those of you who have not yet done so, I will encourage you to participate. I believe that you will find this form of service to be both intellectually challenging and most satisfying.

And for those of you who have become so frustrated by the state of politics in our nation that you are reluctant to engage in such endeavors, I have a short history lesson and a forecast for you.

One hundred years ago, Congress refused to reapportion the House according to the 1920 census, afraid that reflecting the shift in population from farm to city would put at risk the Volstead Act and Prohibition, the divisive issue of the day! In fact, reapportionment had to wait until the 1930 census, in clear violation of the Constitution! And yet, in spite of the fractious debate in the public and in Congress, our great experiment in democracy survived and our nation endured to defeat the existential challenges of World War II in Europe and the Pacific. I will offer my prediction that we too will surmount our current challenges and help provide the leadership that the world has come to expect from the United States!

NAE President’s Address

Thank you, Don, for emphasizing the role of service expected of members of the NAE.

I share your optimism for the future because the engineering profession has adopted a culture of service. To quote NAE Vice President Wes Harris, “we will do great things and do good things” for the betterment of society. Engineers must be socially responsible in their work and also professionals who see the glass half full, not half empty.

What initially started as the National Academy of Sciences in 1863 by an act of Congress, signed by Abraham Lincoln, has since grown to include: the National Research Council, formed in 1916; the National Academy of Engineering, formed in 1964; and the National Academy of Medicine, formed in 1970.

Today, we are known as the National Academies of Sciences, Engineering, and Medicine, or simply, the “National Academies.” Our name has changed to better reflect the breadth of our focus areas; however, the core of our mission remains the same: “The Academy shall, whenever called upon by government, investigate, examine ... and report upon any subject of science or art...”

With the changing times, the National Academies has expanded its role. While we exist to provide independent, nonpartisan, technical advice to the government and public; we also promote the advancement of science, engineering, and medicine, and we catalyze innovation to the benefit of society.

Through a variety of efforts, the National Academies encourages education and research, recognizes outstanding contributions that benefit society, and promotes public understanding of science, engineering, and medicine.

There are seven program units—previously referred to as the National Research Council—that serve as the operating arms of the National Academies. Through the leadership of these divisions and the volunteers who provide their time and expertise, the National Academies of Sciences, Engineering, and Medicine is the trusted voice for evidence-based studies, reports, and discussions that address the science, engineering, technology, medicine, and policy issues of the day. The depth of knowledge and diverse perspectives that you—our members—bring to the table make reports and studies from the National Academies “the gold standard.” The convening power of the National Academies—to bring together the best minds in sciences, engineering, and medicine—is its most important asset.

Many of you took part in the Big Picture Expo yesterday and became familiar with activities of the NAE and the National Academies. I hope you discovered opportunities to engage in the work of the National Academies.

In 2022, 54% of our members and 25% of our international members participated in activities of the
National Academies generally, and the NAE specifically, by serving on committees, lending their expertise to reports, and taking an active role in our member elections.

Induction into the NAE is a “commencement.” It is the beginning of important service to the nation and to the engineering profession. You are also role models for other engineers, especially younger ones.

The founding members of the NAE, pictured here at the first annual meeting of the NAE in 1965, were giants in their field. Of the original twenty-five founding members, fifteen are pictured. Fifty-two percent of the twenty-five represented business and industry. Thirty-six percent represented universities and 12% worked in national laboratories or the military.

I have circled Fred Terman in the photo. He was dean of engineering and then provost at Stanford in 1964. Terman was a mentor to Hewlitt and Packard—of HP fame. He did his PhD at MIT under the supervision of Vannevar Bush, an electrical engineer who was the leading advocate for the formation of the National Science Foundation and author of the well-known 1945 report *Science—The Endless Frontier*.

A hallmark of the NAE is the significant representation of members from industry who bring expertise and perspectives about combining scale and costs not found in academia or government. Of the three Academies, the NAE is the only one with a significant membership from industry. This inclusion is very important. Business and industry are central to innovation and the application of engineering principles. The voices of both business and academia are needed if we are to provide sound advice to the government and public about technology and issues that can, and should, be addressed by engineering.

What is missing in this photo is diversity—diversity of gender, and diversity of race and ethnicity—which would bring a variety of perspectives that enhance the creativity of engineering.

And the dress code is remarkably uniform!

This was the beginning of the NAE. Let’s forward to the present. Quite a difference!

The members and international members of the class of 2023 are representative of the United States and the world today. You bring knowledge, experiences, and perspectives that are unique to your backgrounds—and of great value to the engineering profession.

To quote Theodore von Karman, the first recipient of the Medal of Science and an aeronautical engineer, “...Engineers create what never has been.” Creativity and diversity are very closely linked.

The NAE membership today better reflects our population and values. We aim to increase representation from industry and among women and minority populations and include outstanding engineers in both established and emerging technologies.

One fact that jumps out to me is that 46% of our new members are naturalized US citizens. We are proud of this result and its recognition of the value of immigrants to the health and vitality of our country.

Today, with 2,370 US members and 314 international members, the NAE embraces another chapter of reaching for new frontiers of innovation to address pressing challenges nationally and globally.

In 2021, the NAE leadership revisited its direction. With input from members and staff, we developed a new strategic plan to provide insights, leadership, and direction—with a focus on people, systems, and culture.

Our commitment to the nation, our profession, and our members is prioritized in the “four I’s”:

- Identify and inform the frontiers of engineering theory, practice, and education;
- Increase engineering talent through a strong commitment to diversity and inclusion;
- Instill a culture of ethical and environmental responsibility in engineering; and
• Improve capabilities and competencies for dealing with complex systems.

I will now highlight several activities that show a sampling of the work that the NAE is involved in.

Climate change and its potential impacts represents a pressing global issue. Scientists have done a great job of determining the “what”—what is happening, and what must be done. Engineers must develop the “how.”

The NAE President’s Business Advisory Committee took the lead and produced a series of papers on “Engineering the Energy Transition” toward net zero carbon emissions. These papers were published in the summer 2023 issue of The Bridge, a quarterly of the NAE that can be downloaded from our website. The articles in this issue focus on the “how” to achieve a net zero carbon energy ecosystem. They address many topics from “Electrification of Manufacturing Processes” to “The Electric Grid and Severe Resiliency Events.” I encourage you to look at this publication.

One of the NRC’s most recently released reports, Laying the Foundation for New and Advanced Nuclear Reactors in the United States, reviews the role nuclear reactors can play in the decarbonization of our energy ecosystem and the key challenges that must be overcome at the technical, economic, and regulatory levels.

Both “Engineering the Energy Transition” and Laying the Foundation for New and Advanced Nuclear Reactors showcase the NAE’s efforts to keep a spotlight on energy and sustainability—which are top issues of today and will remain so for some time in the future.

One of our headline programs is The Grainger Foundation Frontiers of Engineering conferences, which bring together a select group of “young” (under forty-five years old), emerging engineering leaders from industry, academia, and government labs to discuss pioneering technical work and leading-edge research in various engineering fields and industry sectors. These conferences are held annually in the United States but also include bilateral events with the European Union, Germany, Japan, and China in alternate years.

I note that 161 Frontiers of Engineering alumni have been elected to the NAE after their participation. That is 10% of all NAE members elected since 2003. The participants are very talented young engineers! I ask everyone here today who has participated in a Frontiers of Engineering symposium, please stand.

Impressive! The Frontiers of Engineering program has had a very large impact not only on the NAE but also on our academic and industrial enterprises. We are very proud of the program and its participants.

For more than twenty years, the NAE’s EngineerGirl website has inspired young women and girls to become engineers. Since its inception as a website, EngineerGirl has grown into a program that includes chats with mentors, a writing contest, and an Ambassador’s Program, which engages high school students in developing engineering activities for middle school students in their community.

Earlier this year, EngineerGirl was recognized by the National Science Board with its 2023 Science and Society Award for “extraordinary efforts to increase participation and diversity in the science and engineering fields.” We are very proud of EngineerGirl. Plans are underway to expand the program offerings to include all underrepresented groups.

We need to reach tomorrow’s students today. We need to introduce them to engineering—in all its many facets. And we need to encourage students to pursue a career in engineering if we are to keep pace with the increased need for future engineers.

We must also reach the public in general and convey the importance of engineering to their daily lives. The word “engineering” often gets lost when we talk about Science and Technology. We must consistently push the word “engineering” back into the conversation if we are to raise awareness.

Last spring, the NAE created its “Calling All Big Thinkers” public service campaign. Launched nationwide, these 60- and 30-second public service announcements showcase the many facets of engineering in an upbeat, motivating way.

In addition, the NAE, in collaboration with the University of Southern California Viterbi School of Engineering, launched The Circuit. This social media-based engineering news show highlights current engineers and engineering students working on real-world problems, making innovative advancements and creating cutting-edge technological solutions. Weekly episodes are posted each Thursday on all major social media channels. The Circuit is playing on the monitor in the Great Hall throughout the Annual Meeting. If you haven’t viewed recent episodes, I encourage you to do so.

The “Calling All Big Thinkers” campaign videos and The Circuit episodes can be viewed from the NAE YouTube channel. Be sure to share them with your colleagues, students, and social networks. Engage with us and spread the word about engineering!

It is important to point out that the National Academies are not
part of the government, and this is by design. This ensures that the essential work we do remains objective and credible. One result of this independence is our dependence on philanthropy. About 64% of the NAE’s operating budget derives from past and current donations by our members, foundations, corporations, and other partners. Your leadership, now more than ever, is critical to the success of efforts to advance the NAE to an even higher level.

The Campaign for Leadership in a World of Accelerating Change seeks to support effective, action-oriented activities that enable and empower the NAE to be the trusted source of engineering advice for creating a healthier, more secure, and more sustainable world. Yes, the world is changing. Yes, engineers have a leadership role to play. Yes, we can and will lead the change.

I would like to thank the NAE staff who make our organization work so well. It is a wonderful group of individuals, and they make good things happen. We owe them a lot.

Also, thank you to the remarkable officers and councillors who govern the NAE. They serve the organization with integrity and dedication.

Recognizing the work of so many reminds me of a quote by Helen Keller, “Alone, we can do so little; together, we can do so much.” With that in mind, I ask the family members of today’s inductees to please stand. Your patience, love, and support played a large part in the lives of our inductees, and we are grateful to you. Let’s give a round of applause to the family members!

Before we begin the induction ceremony, I want to briefly address a question that I know all of you have on your mind: What is the difference between a scientist and an engineer. To answer this important question, I thought of a story told to me by a friend:

“A scientist and an engineer went hiking in the mountains. At the end of the day, they pitched their tent, enjoyed dinner, and went to sleep. After a few hours the engineer wakes the scientist and says, ‘Look toward the sky. What do you see?’

The scientist replies, ‘I see millions of stars.’

The engineer says, ‘What does that tell you?’

The scientist says, ‘Astronomically speaking, it tells me there are millions of galaxies and potentially billions of planets. Astrologically, it tells me that Regulus is in Leo. Timewise, it appears to be approximately 3:30 in the morning. Weather-wise, it seems we will have a beautiful day tomorrow.’ Then the scientist turns to the engineer and says, ‘What does it tell you?’

The engineer replies, ‘Somebody stole our tent!’

If you’re ever asked, now you know the difference between an engineer and a scientist.

2023 Simon Ramo Founders Award
Acceptance Remarks by Robert W. Conn

The 2023 Simon Ramo Founders Award was presented to Dr. Robert W. Conn, Walter J. Zable Distinguished Professor of Engineering and dean, emeritus, Jacobs School, University of California, San Diego, “for shaping national science and technology policy through leadership in academia, business, and philanthropy and for seminal contributions to fusion engineering.”

Thank you very much, John. And good morning, everyone.

I must tell you that when John called me about the Founders Award about three months ago, it really just took my breath away—one person a year since 1966, and the very first awardee! Vannevar Bush. Yes, that Bush, President Roosevelt’s wartime science advisor and author of the famous report, “Science, the Endless Frontier.” That’s called “setting the bar high.” I literally shook in my chair, and frankly, tears came to my eyes.

It’s also hard to describe what it feels like to have this award come from you, my peers. After all, it’s you, my fellow NAE members, choosing me for this rare and prestigious award. I still say to myself, “You’ve got to be kidding!”

I am, of course, truly honored, and so very appreciative.

Engineering is purpose driven. It is about discovering things, designing things, building things, and solving problems. It’s about having inspiring insights and providing leadership, all with the aim of creating a better future.

Engineering is also about service and giving back, often through service on national committees to help the country develop and implement the best possible policies in the areas of science, engineering, medicine, our educational enterprise, and our national defense.

Many of you are newly elected this year—my hearty congratulations.
And I say to you, our country’s finest engineers, the country needs you. I urge you to consider providing the nation with your insights on the policy front when the opportunity arises. You now have the imprimatur to make your voice heard.

As for me, I would not be standing here were it not for all the colleagues with whom I’ve worked over five decades at three academic institutions, in business and venture capital, and in the world of philanthropy.

My first working decade was spent at the University of Wisconsin in Madison, where, with many of my colleagues, we established the then new field of fusion engineering. That was the 1970s.

And one colleague was my closest partner, Jerry Kulcinski. Jerry is an Academy member, an extraordinary person, and he and I were perfectly complementary in skills and knowledge. That’s what allowed us to create this new field.

My years at UCLA, through the 1980s, were when I first really got involved in institution building and in national policy issues.

It was also a decade of entrepreneurship. Together with my graduate student, Greg Campbell (another partnership), we founded in 1986 what became a successful semiconductor equipment company.

What a ride that was! I learned a great deal about “engineering” a successful business and about industry, finances, leadership, and partnerships.

At UC San Diego beginning in 1994, I was given the opportunity by the chancellor, Dick Atkinson, to transform and grow a school of engineering. Over a decade, it did grow—in size, quality, reputation, and rankings, and we ensured its future by working with philanthropists and industry on major gifts and partnerships.

One example with national implications was working with the Whitaker Foundation in the mid-1990s to convince them that what was needed by the country, not just by UC San Diego, was support for bioengineering infrastructure—the newly emerging departments of bioengineering needed new buildings.

They agreed to provide $20 million grants per awardee to construct bioengineering buildings, and along with Penn, we were the first awardees. But with that, we helped ensure bioengineering’s future across the country.

Another set of gifts from Irwin and Joan Jacobs, as the poet said, made all the difference. Together with them, we transformed the school. And today, the Jacobs School has the largest endowment of any public engineering school in the country.

Irwin is another NAE member, and was the co-founder, CEO, and board chair of Qualcomm. He and his wife Joan’s extraordinary endowment gifts, and the annual payout therefrom, were key to helping the Jacobs School attract great faculty and students while inspiring others to give. All this allowed the Jacobs School to grow along every axis.

I guess there’s a theme here: Nothing gets done alone, but don’t be afraid to think big.

For my last formal hurrah, I had the opportunity to lead The Kavli Foundation, learn and lead in philanthropy, and work with Fred Kavli. It proved to be a phenomenal experience, and one that’s best had towards the end of one’s career, when a bit more wisdom complements expertise and experience.

Perhaps the major outcome during those years was the support provided by the foundation very early on that catalyzed an initiative to map the functioning brain over the next decade or two. That initiative became President Obama’s BRAIN Initiative in 2013, the nation’s first science grand challenge problem of the twenty-first century.

By the way, we happen to be sitting in the Fred Kavli Auditorium. After Fred’s death in 2013, the foundation was looking for a way to honor him. I contacted the president of the Academy back then, Ralph Cicerone, for ideas. Long story short, we ended up providing the Academy in 2017 with a major endowment gift. And as a tribute to Fred Kavli, the Academy
The 2023 Arthur M. Bueche Award was presented to Dr. David L. Tennenhouse, senior advisor, National Science Foundation, “for the conception, implementation, and stewardship of information technology R&D involving unique partnerships among academia, industry, and government.”

The grand bargain is that society funds research, and our community ensures the nation’s health, prosperity, and security.

Today, the US and the world are facing new challenges, including global competition, societal challenges, and the sustainability challenges we are discussing this morning. These challenges require that we accelerate the translation of research into practice through new partnerships across the three legs of the Bueche triangle: industry, government, and academia.

That is why I have joined the NSF’s new TIP Directorate. Whatever parts of the triangle you work in, let’s live up to our end of the bargain and engineer a future in which the entire US population is healthier, more prosperous, and more secure.

I am speaking today in my personal capacity and not as a representative of the NSF—and these comments try to bring an engineer’s perspective to the grand bargain.

In terms of prosperity, engineering has been a path to upward social mobility. I am an immigrant, and I am fairly certain that a large fraction of the NAE are also immigrants or the children of immigrants. I encourage the Academy to champion the role immigrants play in our profession and as drivers of the US economy—not just the immigrants who come here with amazing educations but all of the immigrants. They enrich us through their passion, work ethic, and risk appetite—key ingredients of innovation.

If engineering continues to provide a path for immigrants and their children, they will provide a path to continued US prosperity.

Engineers take accountability for failures and strive to learn from them. We have a deep passion for getting to the bottom of how things work and how to make them better, safer, and more efficient.

Dan Goldin, who was the NASA administrator, once blurted out that NASA had scientific triumphs and engineering disasters. My first reaction was, “OMG, I need to call Bill Wulf and tell him the NAE needs a new PR team.” Then I connected Dan’s comment to the key engineering lesson I was taught: When a bridge falls down, people are killed. We are accountable.

My own field of information technology has delivered tremendous social and economic value. I am excited about the endless frontier.
of new technologies that we have yet to discover—but my colleagues and I need to rededicate ourselves to engineering values. For example, it’s not okay to field systems that lack privacy guard rails or systems in which the provenance of the data is unknown, in which facts can’t be distinguished from fiction, and in which our shared models of truth are compromised.

But, today, I’d like to enlist your help in making sure the US wins two critical races in which engineering values should play a larger role.

One is financial technology. Until immigrating to the US, I didn’t realize the role capital formation plays in innovation and the role innovation plays in financial markets. If we are going to continue to lead, then we must continue to have the most innovative financial system.

Today, fintech is disruptively enabling new forms of digital assets. Our fear of the unknown could cause us to reject these technologies and allow other countries to race ahead.

Instead of a crypto winter, let’s embrace fintech as a branch of engineering. Let’s figure out how these technologies work and reformulate them in ways that align with our values—and, in doing so, renew the US franchise on financial innovation.

In almost every field, AI, the combination of big datasets and neural networks, is achieving dramatically better results than classical methods.

Grounding engineering in more real-world data has to be a good thing. So, let’s be sure to win the data race. Whatever your area of specialization, please be a leader in bringing a “big data” culture to your subdiscipline—a culture that involves the collection, curation, and privacy-enhanced sharing of data at a vast scale.

I’m eager to engage in the policy discussion around AI. But, between us engineers, the real catch is that we don’t know how neural networks work.

I love the results neural nets achieve. Now that we know those results are possible, CS researchers must reinvent AI. Let’s win the race to discover approaches to AI whose inner workings are understood and that get even better results.

We also need to double down on making sure that the next generation of engineers retains a thirst to discover how things work—and don’t just blindly accept the answers AI provides. Let’s guide them to uncover new insights by fusing traditional engineering models with the new data-driven models.

Two weeks ago, Eric Schmidt suggested that AI could enable a 2x across-the-board productivity gain.

That made me wonder: How much more productive could engineers become? Why not target a 4x gain? Wouldn’t productivity be a better basis for us to compete on than sheer numbers of engineers?

With that suggestion, I’d like to thank the Bueche family, the nominators, the award committee, my colleagues and team members, and especially my amazing wife and family for this award.

2023 Golden Bridge Society Dinner Highlights

The 2023 Golden Bridge Society dinner, celebrating the NAE’s most generous members and friends, was held October 1 in the Great Hall of the National Academy of Sciences Building. Hosted by NAE President John L. Anderson and his wife Pat, this yearly event recognizes the generosity members and friends have shown the NAE over the years.

This year’s dinner saw ten recognition awards presented to our Lifetime Giving Society members. For lifetime giving of $1M or more, Lincoln Society medals were presented to Norm Augustine, James and Marci Truchard, and Robin McGuire.

For lifetime giving of $500,000 to $999,999, Franklin Society medals were presented to John and Pat Anderson and Wesley Harris. For lifetime giving of $250,000 to $499,999, Curie Society medals were presented to Chau-Chyun Chen and Robert and Lee Sproull. For lifetime giving of $100,000 to $249,999, Einstein Society statuettes were presented to Ed Frank and Susan Graham. For lifetime giving of $20,000 to $99,999, we welcomed Anjan and Francy Bose, Fiona Doyle, Efi Foufoula-Georgiou, Xuedong and Yingzhi Huang, Chen-Ching Liu and Hiromi Okumura, Guru Madhavan and Ramya Ramaswami, Charles Sukup, and Darsh Wasan into the NAE’s Golden Bridge Society. Finally, for their documentation of a planned gift, Tom and Bettie Deen received a Heritage Society medal.

The night also included highlights of the NAE’s $100 million Campaign for Leadership in a World of Accelerating Change, a tribute to former NAE President Wm. A. Wulf, and an introduction to the NAE’s upcoming 60th anniversary giving challenges.

Philanthropic support from NAE members and friends plays a vital role by sustaining approximately 60% of the NAE’s operations. Through
Attendees enjoying the 2023 Golden Bridge Society Dinner in the Great Hall of the National Academy of Sciences Building.

contributions to the unrestricted Independent Fund, program-specific funds, or endowment funds, the generosity of our donors enables the NAE to fulfill its mission to “advance the welfare and prosperity of the nation by providing independent advice on matters involving engineering and technology, and by promoting a vibrant engineering profession and public appreciation of engineering.”

To join one of the NAE’s Lifetime Giving Societies or the Campaign for Leadership in a World of Accelerating Change, contact Radka Nebesky at RNebesky@nae.edu or 202-334-3417, or Stephanie Halperin at SHalperin@nae.edu or 202-334-1842.

* Bolding denotes NAE membership.

The Grainger Foundation Frontiers of Engineering 2023 Symposium Held at the University of Colorado Boulder

This year’s US Frontiers meeting was hosted by the University of Colorado Boulder College of Engineering and Applied Science, September 10–13. NAE member Timothy Lieuwen, interim chair of the Daniel Guggenheim School of Aerospace Engineering and Regents’ Professor, Georgia Institute of Technology, served his third and final year as chair of the organizing committee and the symposium. The sessions were Resilience and Security in the Information Ecosystem, Engineered Quantum Systems, Complex Systems in the Context of Health Care, and Mining and Mineral Resource Production.

The session on resilience and security in the information ecosystem examined the sociotechnical issues underlying the threats of disinformation, misinformation, and rumoring to civic discourse on online social platforms. Speakers also discussed potential solutions for designing, engineering, and building a better information ecosystem. The first speaker, Kate Starbird (University of Washington), described the factors that have contributed to vulnerabilities in the information ecosystem and the strategies malicious actors use to exploit them. Next, Deen Freelon (University of Pennsylvania) talked about asymmetries in the information space, obstacles to progress, and tools that would ensure we can maintain a resilient information ecosystem. Yoel Roth (former global head of trust and safety at Twitter) then gave an account of his first-hand experiences combating these issues and where companies might go from here. The final speaker, Rebekah Tromble (George Washington University), discussed ways to bridge the gap between engineering and policy.
makers in order to deploy interventions that mitigate these threats.

The merging of quantum mechanics and information science in the late twentieth century opened many possibilities to perform computations and operations that are not possible using conventional, classical physics approaches. Advances in basic research have enabled a multitude of proof-of-principle experiments verifying the demonstration of quantum-based advantages. However, the large-scale, highly engineered systems needed to push quantum into new domains remain very challenging to reliably construct and operate. Alicia Kollár (University of Maryland) started the session with a talk about the fundamental challenges of scaling up quantum systems and the exploration of novel uses. Next, Kathy-Anne Soderberg (US Air Force Research Laboratory) explained how the Department of Defense is pushing the boundaries of the leading platforms for large-scale quantum systems for government applications. Robert Smith (HRL Laboratories) concluded the session with a presentation on the software challenges that physicists and engineers in industry are tackling to lay the groundwork for commercial quantum technology advances now and in the future.

The third session focused on the complexity of the healthcare system, from modeling human biological systems to population-level decisions. The session started with a talk by Rodrigo Cristofoletti (University of Florida) about engineering human organoids and organs-on-chips that model diseases; this reduces dependence on animal testing in the drug development process. Turgay Ayer (Georgia Institute of Technology) then spoke about improving blood collection operations at the American Red Cross through a dynamic programming approach that systematized the selection of collection sites. Guadalupe Hayes-Mota (Healr Solutions) described a centralized technology approach aimed at delivering drugs faster and more efficiently to patients, particularly in the case of natural disasters. The final speaker, Sze-Chuan Suen (University of Southern California), talked about how framing public health campaigns as optimization problems, as exemplified by her work with TB-related campaigns in India, maximizes limited public health resources to stop the spread of diseases.

The technical portion of the meeting concluded with a session on mining and mineral resource production. This topic was suggested by NAE member Corale Brierley (Brierley Consultancy LLC) and had not been covered at previous US or bilateral Frontiers of Engineering meetings. Given that over the next twenty years many scarce and poorly-concentrated materials will experience unprecedented demand to meet sustainable energy needs, it was an apt topic for an FOE meeting. Isabel Barton (University of Arizona) opened the session with a historical perspective on how mineral resources have formed the basis of civilization and where trends are moving today. Joshua Werner (University of Kentucky) then spoke about the challenges presented by today’s materials needs and the interplay between mining and recycling that is required to facilitate future growth. The last talk by Nina Astillero (ioneer, Ltd.) described how a modern mining project in Nevada will provide the critical materials of lithium carbonate and boric acid in a sustainable way.

Meet and Connect breakout sessions provided an opportunity for attendees to share their research and technical work so participants could get to know more about each other relatively early in the program. On the second afternoon, attendees toured various sites on campus, including the Joint Institute for Laboratory Physics, the building that houses Ann and H.J. Smead Aerospace Engineering Sciences, and several engineering laboratories where research on precision laser diagnostics, new types of hybrid superconducting and semi-
FOE Alumna Wins 2023 CAETS Communication Prize

Caitlin Howell, a 2023 NAE Gilbreth Lecturer and former FOE participant, was awarded the 2023 CAETS Communication Prize on October 9 in Zagreb, Croatia. Dr. Howell’s winning entry, “Deciphering Nature’s Secrets: Bio-Inspired Solutions for Antibiotic Resistance,” may be viewed on the NAE YouTube channel.

“Dr. Howell was nominated for the CAETS Communication Prize by the National Academy of Engineering as part of NAE’s ongoing efforts to recognize outstanding early career engineers,” said NAE President John L. Anderson. “Her research has led to discoveries in methods to resist infection in medical devices without the need for antibiotics. We are very excited that she is being recognized on an international level,” he added.

Howell was selected from among thousands of early career engineers to participate in the NAE FOE Symposium in 2022. Based on her FOE presentation, she was one of four individuals selected to be a Gilbreth Lecturer at the 2023 NAE National Meeting.
where she presented “Materials-Based Approaches to Prevent Biofilm-Associated Infections” to more than 200 high school students. Based on feedback from that presentation, she was selected to represent the NAE for the CAETS Communication Prize.

As associate professor of biomedical engineering, and head of the Biointerface and Biomimetics Lab at the University of Maine, Howell and her team have worked on drawing inspiration from nature and working across the disciplines of biology, chemistry, and materials science to address major issues in human health. Inspired by how the human body controls its large, diverse bacterial cohorts, her work has led to discoveries in methods to resist infection in medical devices without the need for antibiotics.

Dr. Howell and her team also focus on developing new ways to use biodegradable and renewable materials such as cellulose in biomedical applications. She received her BS and MS degrees in biology from the University of Maine and a PhD in physical chemistry from the University of Heidelberg, Germany.

The CAETS Communication Prize is an annual competition of the International Council of Academies of Engineering and Technological Sciences (CAETS) that is designed to encourage technological scientists and engineers around the world to effectively communicate in a simple and engaging manner with general audiences. The award aims to amplify the impact engineering has on governments and the general public by communicating the important role of technology in society. Entries are in the form of a short video that explains the societal importance of technological breakthroughs and engineering successes in a manner that is easily understood by, and of interest to, broad audiences. All entries must be endorsed by a CAETS member academy.

According to CAETS, the prize is awarded to the “most outstanding audiovisual communication of excellence and innovation in technological sciences or engineering.” The award was presented during CAETS2023.
The 2023 EU-US Frontiers of Engineering symposium was held October 15–18 at Nokia Bell Labs in Murray Hill, New Jersey. The NAE partnered with the European Council of Applied Sciences, Technologies and Engineering (Euro-CASE) to carry out the event. Muriel Medard, NEC Professor of Software Science and Engineering in the Department of Electrical and Computer Engineering at Massachusetts Institute of Technology, and Marko Topić, professor and chair of the Department of Electronics at the University of Ljubljana, cochaired the symposium.

NAE Executive Officer Al Romig, Euro-CASE Secretary General Patrick Maestro, Bell Labs Solutions Research President Thierry Klein, and Bell Labs Core Research President Peter Vetter welcomed the group at the meeting’s opening.

The two-and-a-half-day event brought together fifty early-career engineers from US and European universities, companies, and government labs for presentations on leading-edge developments in four topics: additive manufacturing, clean hydrogen, quantum science and technology, and computational impacts on the life sciences. Participants attended from the United States and fifteen EU countries: Austria, Belgium, Denmark, France, Finland, Germany, Ireland, Italy, Norway, Poland, Portugal, Romania, Slovenia, Spain, and the United Kingdom.

Additive manufacturing (AM) is transforming the design, manufacture, and function of many components and products, and it has applications in many fields such as aerospace, automotive, and healthcare. This session discussed the challenges associated with AM’s adoption by industry and highlighted areas for future growth. Christopher Hovanec (Department of the Navy) described how policy and investments in AM have accelerated foundational, cross-cutting clean energy materials and manufacturing. Serena Graziosi (Politecnico Di Milano) talked about design for manufacturing and its importance for the future of AM. Connor Myant (Imperial College London) focused on bioprinting technologies and promising results for applications in medicine. Jason Jones (Hybrid Manufacturing Technologies) closed the session with a review of post-processing for AM, which is critical to the successful adoption of AM technologies.

Chemical manufacturing processes through steam-methane reforming have a significant carbon footprint and, as a result, utilization of hydrogen has been limited to industrial...
applications as a feedstock. However, the rapid growth in renewable electricity has opened the door for alternative manufacturing methods that can completely decarbonize its production. The second session on clean hydrogen highlighted R&D related to clean hydrogen on the entire value chain, particularly trends in the industrial sector. Presentations covered membranes for low-temperature water electrolysis and fuel cells (Christopher Arges, Pennsylvania State University), hydrogen production using low-temperature proton exchange membrane electrolysis (Iryna Zenyuk, University of California, Irvine), solid-state hydrogen storage technology (Enass Abo-Hamed, H2GO Power), and monitoring and diagnostics tools for fuel cell systems (Vanja Subotic, Graz University of Technology).

Global efforts are underway to translate discovery-based quantum science to the engineering domain to actualize quantum technologies and commercial propositions. Leading application areas such as computing, communication, and security are poised to touch our everyday lives in sectors as diverse as health care, finance, and defense. The first speaker, Caterina Foti (Aalto University) provided insights on how to develop a quantum literate workforce of engineers and technology users and demystify quantum for non-specialists. Next, John Watson (Microsoft) discussed efforts in industry towards scalable quantum computing and the vast engineering challenges required to make quantum computers a reality. Daniel Apon (MITRE) provided perspectives on the threat quantum computers pose to data security and the research into quantum cryptography that promises unhackable encryption. The final speaker, Sarah Thomas (Imperial College London), focused on optical quantum emitters and memories, which are essential for the realization of quantum communication.

The final session on the computational era of life sciences focused on the increasingly important role that computational simulation is having across life science, from the micro level (molecular simulation) to the macro level (simulation within epidemiology). Speakers in this session covered data simulation to enhance statistical rigor in genomics data science (Jessica Li, University of California, Los Angeles), molecular dynamics and multiscale modeling to investigate cellular processes (Ariane Nunes Alves, Technical University Berlin), and machine learning to predict how disease prevalence will be influenced by future climate change (Bruno Cavalho, Barcelona Supercomputing Center).

Abstracts of the papers and presentation slides where permission has been granted can be accessed in the List of Sessions for the 2023 EU-US FOE at www.naefrontiers.org. In addition to the formal presentations, poster sessions preceded by flash poster talks were held over two days. These served as both an icebreaker and an opportunity for all participants to share information about their research and technical work. A revamped schedule with shorter talks and discussion allowed more time for informal networking.

Peter Vetter, president of Bell Labs Core Research, gave the dinner speech on the first evening. This is the one presentation at a Frontiers of Engineering meeting given by a senior-level executive. Dr. Vetter described the culture at Bell Labs as collaborative, multidisciplinary, and focused on developing strong technical competence and leadership potential. He also provided insights on his own career journey and asked attendees to reflect on the defining moments that got them to where they are and how they would define their purpose.

During one of the networking sessions, attendees were able to view items in the Bell Labs Technology Showcase, including the first transistor; a flight backup unit of Telstar, the world’s first communications satellite; and tributes to the many achievements of Bell Labs researchers. On the second afternoon, Bell Labs organized tours of five research areas: quantum computing, 6G radio-on-glass, autonomous industrial monitoring, fiber sensing, and its anechoic chamber.

Financial support for the symposium was provided to the NAE by The Grainger Foundation and the National Science Foundation. The next EU-US FOE will be held in 2025 in France. The NAE has been holding Frontiers of Engineering symposia since 1995 and the EU-US FOE since 2010. For more information about the symposium series or to nominate an outstanding engineer to participate in future Frontiers meetings, contact Janet Hunziker at the NAE Program Office at JHunziker@nae.edu. The FOE website is www.naefrontiers.org.
2023 Technology for a Quieter America Workshop: 
Occupational Noise Exposure—Risks and Controls

The 2023 Technology for a Quieter America (TQA) workshop, “Occupational Noise Exposure—Risks and Controls,” was held at the Keck Center in Washington, DC, on October 23-24. The event was an NAE member-initiated workshop, carried out with the support of the Institute of Noise Control Engineering (INCE) Foundation and the NAE. Thirty-five people representing various stakeholders in occupational noise met to discuss the current state of occupational noise exposure and opportunities to manage occupational noise risks from many perspectives.

Major topics discussed included: the state of occupational noise exposure in the United States, whether workers are being adequately protected from overexposure to occupational noise, surveillance of noise and occupational hearing loss in the United States, the quality of life and economic impacts of worker over-exposure (at the individual, employer, and nation levels), models for the prevention of occupational noise-induced hearing loss, the prevention of overexposure, the importance of quieter machines and processes, and opportunities for engineering solutions, other than hearing protection, that can reduce overexposure. Other topics included the role of hearing loss as a contributor to dementia and the prospect of hearing preservation with pharmaceuticals. A summary report of the workshop will be issued by INCE in the coming months.

Year-End Update for the Ligler-Wagoner Challenge for The Grainger Foundation Frontiers of Engineering

The Ligler-Wagoner Challenge for The Grainger Foundation Frontiers of Engineering launched in November of 2021. Since then, past participants and friends have donated more than $125,000, bringing us over 60% of the way to our $200,000 goal. Thank you to everyone who has donated. We truly appreciate your support.

Your generosity is helping to boost the profile of this signature program and ensure its career-changing impacts for future generations of engineering leaders.

Help us reach our goal by donating before the end of the year. Every donation is being generously matched 1:1 by Frances and George Ligler (NAE ’05 and ’17) and Robyn and Robert (NAE ’95) Wagoner. If you would like to learn more about the challenge, access information on how you can make a gift, or hear from other challenge donors, visit www.naefrontiers.org.
NAE Welcomes New Staff

SUDHIR SHENOY has joined the NAE Program Office team as an associate program officer. Sudhir Shenoy recently completed his PhD in the computer engineering program at the University of Virginia (UVA). His dissertation focused on integrating theory of mind and reinforcement learning into a framework for developing emotion adaptive social robots for use in healthcare environments for pain management and mental health wellbeing. Sudhir holds a master’s degree in computer engineering from UVA and an undergraduate degree in electrical engineering from Jain University in India.

Sudhir also has training in science and public policy and in engineering ethics at UVA. As a part of this training, he worked as an intern at the NAE during the summer of 2019. He has taught several engineering courses as a teaching assistant and introduced new robot ethics courses as an instructor at UVA. With experience in various teaching, research, and leadership roles at UVA, he is looking forward to bringing his multifaceted skills and expertise to the Academies. In his free time, he enjoys hiking in the Shenandoah mountains, going to live music events for swing dancing, nature photography, and filmmaking.

Aligning with NAE’s people, systems, and culture objectives, his efforts will focus on assisting projects such as PEER and CESER. We look forward to the innovative contributions Sudhir will undoubtedly make to our team, and we’re excited to have him on board as part of the NAE family. You can contact him at sshenoy@nae.edu or (202) 334-2303.

ROBBIN WU has joined the President’s Office as administrative assistant, where she will provide support for day-to-day functions. Robbin will also be a critical resource to the Membership Office, with responsibilities for member projects and events, including the Annual Meeting. Robbin was an executive assistant at the Johns Hopkins Applied Physics Laboratory for more than five years and prior to that was the executive assistant at the Universities Space Research Association for seven years. Her experience with calendar management, communications, and meetings administration will be a great asset. During her time in those positions, she worked with several NAE members, which helped spark her interest in employment with the NAE. Robbin lives with her husband, their two children, and the family’s golden retriever in the Annapolis area. An active family, they stay busy with kids’ sports. Robbin enjoys exploring recipes/wines, running, and spending time with family and friends. You can reach her via email at rwu@nae.edu or by phone at (202) 334-2976.
Calendar of Meetings and Events

November 14  Bridging the Rural-Digital Divide through Space Virtual
2024
January 11  Understanding Failures in Social Systems: Integrating Biological, Behavioral, and Engineering Insights Virtual
February 8  NAE National Meeting Irvine, California
March 24–26  NAE Regional Meeting Purdue University
April 2  NAE Regional Meeting Texas A&M
April 17  NAE Regional Meeting University of Delaware & Chemours
May 30  NAE Regional Meeting University of California, Davis
Sept 29–30  National Academy of Engineering Annual Meeting

In Memoriam

Luiz André Barroso, 59, Google Fellow, Google Inc., died September 16, 2023. Dr. Barroso was elected in 2021 for contributions to the architecture, design, and performance of energy-efficient warehouse-scale computing.

Toby Berger, 81, professor of electrical and computer engineering, University of Virginia, died May 25, 2022. Professor Berger was elected in 2006 for contributions to the theory and practice of lossy data compression.

Roger W. Brockett, 84, An Wang Professor of Electrical Engineering Emeritus, Harvard University, died March 19, 2023. Professor Brockett was elected in 1991 for outstanding contributions to the theory and practice of linear and nonlinear control systems.

Francois J. Castaing, 78, president, Castaing & Associates, died July 26, 2023. Mr. Castaing was elected in 1995 for the development of highly reliable, high-performance automobiles and for their successful production through innovative organizational structures.

Fredric F. Ehrich, 94, retired staff engineer, General Electric Aircraft Engines, and senior lecturer, Massachusetts Institute of Technology, died August 17, 2023. Dr. Ehrich was elected in 1992 for contributions to the design and development of aircraft gas turbine engines and the technology of rotor dynamics.

Davis Ford, 86, president, Davis L. Ford & Associates, died September 15, 2003. Dr. Ford was elected in 1997 for the application of theory to process design in environmental engineering.

Subhash Mahajan, 83, distinguished professor of material science and special advisor to the chancellor, University of California, Davis, died August 17, 2023. Professor Mahajan was elected in 2005 for advancing our understanding of structure-property relationships in semiconductors, magnetic materials, and materials for light-wave communication.

Harold Mirels, 99, consultant and retired principal scientist, the Aerospace Corporation, died July 2, 2023. Dr. Mirels was elected in 1986 for significant, pioneering work and excellent management of gas dynamics research, and for the invention and development of the continuous-wave chemical laser.

J. Tinsley Oden, 86, professor and founding director, Oden Institute, University of Texas at Austin, died August 27, 2023. Dr. Oden was elected in 1988 for pioneering work in computational mechanics, which significantly advanced the transformation of nonlinear continuum mechanics into a powerful and widely used engineering tool.

Donald E. Ross, 93, retired consultant, Jaros Baum & Bolles, died January 18, 2021. Mr. Ross was elected in 1993 for contributions to design of energy-efficient systems, professional...
and public services, and the nurturing of engineering talent.

William B. Russel, 77, Arthur W. Marks ’19 Professor (retired), Princeton University, died September 24, 2023. Professor Russel was elected in 1993 for research on the influence of polymers on the phase behavior, coagulation, and rheology of colloidal dispersions.

Robert F. Sawyer, 88, professor of energy emeritus, mechanical engineering, University of California, Berkeley, November 17, 2022. Dr. Sawyer was elected in 1993 for research on the influence of polymers on the phase behavior, coagulation, and rheology of colloidal dispersions.

John E. Warnock, 82, chairman, Adobe Systems Inc., died on August 19, 2023. Dr. Warnock was elected in 1996 for the invention and implementation of technologies for computer graphics, printing, and publishing.

Albert R. Westwood, 91, vice president emeritus, Sandia National Laboratories, died July 26, 2023. Dr. Westwood was elected in 1980 for contributions to the understanding, control, and technological application of the environment-sensitive mechanical properties of solids.

Paul Zia, 97, Distinguished University Professor Emeritus, Civil, Construction, and Environmental Engineering, North Carolina State University, died August 16, 2023. Dr. Zia was elected in 1983 for significant contributions to the advancement of structural concrete design practice.
In the early 1970s, when a group of technocrats took the Green Revolution to Bali, Indonesia, the results were catastrophic. They insisted that the island inhabitants redesign the subak—a centuries-old rice paddy irrigation system deeply rooted in the community’s history and values. In place of the sophisticated system with excellent rice yields and means of pest eradication, officials inserted a system of “technology packets” that combined new rice varieties, fertilizers, and an aggressive harvesting schedule, all in the name of increasing production. What they ended up with were decimated rice paddies full of pests and fungus (Lansing et al. 2014; Madhavan 2015).

Had the officials responsibly engaged with the Balinese people and learned about the subak system as well as the community’s values and traditions that supported it, the destructive results of their intervention could have been easily avoided.

Engineers affect society in ways unlike many other professions. They can consciously and unconsciously transform lives and affect generations through their creations, and so they spend years training and countless hours designing, testing, and iterating. However, a fundamental portion of any engineering project, particularly with civic objectives, is far too often overlooked or dismissed: community engagement. We argue that it’s impossible to complete any engineering project successfully without community involvement. And as with Bali, not engaging the public can have pernicious consequences.

The term “community engagement” can and does have multiple connotations depending on how one views it. In general, it is an explicit action focused on working with a community for the community’s benefit (Natarajarathinam et al. 2021). This can take many forms for engineers, such as educational programming, town hall meetings, or even focus groups, but at its core, community engagement should ideally deepen the understanding between the engineers and the community and the impacts a project can have over its intended life course.

A key first step in any engineering project should be to listen and reflect. Who is this project for, and whom is it affecting? This necessitates community involvement in every step of a project, from planning and design through execution and evaluation, and all groups within a community, particularly those traditionally marginalized, need to be identified and included (Bell 2022). The hallmark of engineering design is to operate under constraints. While some contractors may see community engagement activities as an unnecessary delay for a pre-laid schedule, engineering design should also operate with the highest level of accountability. It is vital that everyone who will be impacted by the work be heard and considered.

In far too many cases over the history of modern engineering, underrepresented and marginalized communi-
ties have been overlooked and adversely affected as a result. Without being a member of a community—be that geographical, racial, cultural, or socioeconomic—a person can’t fully understand what it is to be a part of that community: how that community functions, what their needs are, or how something will affect that community. An engineering firm can design a construction project that seems exceptional on paper, and perhaps appealing to investors and policymakers, but what if it doesn’t lead to where the community needs to go or disrupts an ecosystem the community uses in an altogether different way? Or what if a bridge is helpful but far down the list of priority projects that would benefit a community? These are not novel thoughts. Yet, as engineers, we raise them because assuming to know what the best course of action for a community is will only perpetuate the cycle of marginalized communities being handed technology they cannot or do not want to use, or worse, unintentionally being harmed by projects in which they have no input.

Consider another classic example: People around the world depend on burning wood, coal, or other materials in their homes in order to generate heat and prepare food. These stoves often have detrimental health and environmental consequences, so many, many clean stoves have been created to mitigate these effects. And yet millions of people continue to use the harmful stoves. Why? In many cases, the clean stoves don’t function in the context of the end user’s daily life (Ventrella et al. 2020). Had the engineers who created the un-used stoves engaged with the communities they were trying to help in the development phase of the stoves, they could have learned about how the stoves are actually used, what the community’s needs and concerns are, and what stumbling blocks the engineers’ initial assumptions may confront.

Community engagement isn’t a one-way street. The community too needs to learn from engineers in order to become informed—and constructive—collaborators in a project. With a more nuanced understanding of the background, project, and process, community members would be in a better position to inform the project team of related values and concerns in the planning stages—and even to guide the project team. And they are more likely to accept and integrate the value of a proposed or completed project into their lives. The technology being introduced may be safer, “greener,” and cleaner, but common sense suggests that if the intended users don’t see its direct value, they will not accept it (Hanna et al. 2016).

Engineers can’t merely stop at surveying a community’s needs and concerns. They must invest time to share their ideas and the reasoning behind them with the intended community, however controversial. For a technology project with humanitarian intent to be effective, engineers need to discuss and demonstrate the ideas, and prime a conversation based on their comfort levels, buy-in, or dissent. Again, does in-depth community engagement slow a project down? Yes, but by consciously slowing down in this way, projects are better and project teams are more connected with the actual needs of communities, which allows for faster, more prudent advancement overall.

More directly in our work at the National Academy of Engineering, through the Inclusive, Diverse, and Equitable Engineering for All (IDEEA) outreach initiatives focused on K–12 students, we have learned that future engineers want to slow down to better engage with communities. The next generation of engineers, particularly girls and students from other groups under-represented in engineering, are more interested in engineering if they see it as a career where they can meaningfully contribute to social good (Syed et al. 2022). As part of the academy’s EngineerGirl program, established in 2001 to bring national attention to the exciting opportunities that engineering represents for girls and women, high school students have served as ambassadors trained in community engagement. The ambassadors have introduced engineering to younger students in their communities, focusing on students with little access to engineering education and role models. Through their efforts, the ambassadors have introduced thousands of students to engineering who otherwise may not have had the opportunity to explore the subject. Not only do the ambassadors better understand the importance of community engagement through direct action as they pursue engineering careers, but all the participants also now have a better understanding of engineering, which will help them be more informed and responsible citizens in the future. Community outreach and engagement can be a tellingly fulfilling cycle.

Involving community members in the process doesn’t need to be limited to discussions, debates, and demonstrations. The growing movement of “citizen science” can bring community members in as active participants. Exchanging knowledge between the community and the project team is incredibly valuable, but taking it to the next level and making community members collaborators in the project can lead to all participants being more invested and better outcomes overall (Bell et al. 2017).
Monitoring a project after it is complete is necessary for evaluation and future work. This is standard practice in engineering. Going back to the clean stoves example, community members using them can report on functionality, gather readings from monitors, and have follow-up conversations with the project team. This was the case in stove-related sensor projects in Uganda and Honduras, in 2017 and 2018 respectively, and led to beneficial design changes (Ventrella et al 2020). By engaging community members in that monitoring and evaluation process, they become more invested in the project, and the project team continues to learn from the community about how their work is being used and they maintain that connection for future projects.

Engineers have an opportunity to delve into the successful—and not so successful—case studies of community engagement to present a path for more responsible technology development, especially the ones people least understand or are most affected by. As sociologist James Scott observed in Seeing Like a State, while discussing examples of the push for advancement leading to new systems being imposed on communities, “formal schemes or order are untenable without some elements of the practical knowledge that they tend to dismiss” (Scott 1998). Engineers cannot afford to discount the knowledge and existing systems of the communities they aim to serve. If we fail to focus on the “human” part of humanitarian engineering and technology, we’ve lost sight of its purpose.

References


Bell S. 2022. 8 things engineers shouldn’t forget when engaging with communities. Institution of Civil Engineers, Civil Engineer Blog.


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