BASIC ENERGY SCIENCES ADVISORY COMMITTEE
to the
U.S. DEPARTMENT OF ENERGY

PUBLIC MEETING MINUTES
April 5, 2022

Virtual Meeting

DEPARTMENT OF ENERGY BASIC ENERGY SCIENCES ADVISORY COMMITTEE
SUMMARY OF VIRTUAL MEETING

The U.S. Department of Energy (DOE) Basic Energy Sciences Advisory Committee (BESAC) convened a virtual meeting on Tuesday, April 5, 2022, via Zoom. The meeting was open to the public and conducted in accordance with the requirements of the Federal Advisory Committee Act (FACA). Information about BESAC and this meeting can be found at https://science.osti.gov/bes/besac.

BESAC Members Present:

Cynthia Friend, BESAC Chair, Kavli Foundation
Matthew Tirrell, Vice Chair, University of Chicago, Argonne National Laboratory (ANL)
John Allison, University of Michigan
Lynden Archer, Cornell University
Stacey Bent, Stanford University
Joan Broderick, Montana State University
Lin Chen, ANL, Northwestern University
Helmut Dosch, Deutsches Elektronen-Synchrotron (DESY)
Thomas Epps, University of Delaware
Laura Gagliardi, University of Chicago
Jeanette Garcia, International Business Machines (IBM)
Murray Gibson, Florida Agricultural and Mechanical University-Florida State University (FAMU-FSU)
Javier Guzman, ExxonMobil
Frances Hellman, University of California, Berkeley, Lawrence Berkeley National Laboratory (LBNL)
Marc Kastner, Massachusetts Institute of Technology (MIT), retired
Marsha Lester, University of Pennsylvania
Allan MacDonald, University of Texas, Austin
Shirley Meng, University of Chicago
Pietro Musumeci, University of California, Los Angeles
Abbas Ourmazd, University of Wisconsin, Milwaukee
Andrew Stack, Oak Ridge National Laboratory (ORNL)
Esther Takeuchi, Stony Brook University, Brookhaven National Laboratory (BNL)

Designated Federal Officer:

Linda Horton, Associate Director, Office of Basic Energy Sciences (BES)

BES Management Participants:

Bruce Garrett, Director, Chemical Sciences, Geosciences and Biosciences Division
Andy Schwartz, Director, Materials Sciences and Engineering Division

BESAC Committee Manager:

Kerry Hochberger, Program Analyst

Tuesday, April 5, 2022

Friend, BESAC Chair, called the meeting to order at 11:03 a.m. Eastern Time to a virtual audience of approximately 345 people. BESAC members introduced themselves, and Friend led the panel in congratulating **Takeuchi** on receipt of a National Academy of Sciences (NAS) award in the Chemical Sciences.

Research Priorities for Science and Energy, Geraldine Richmond, U.S. Department of Energy Under Secretary for Science and Innovation

As the solutions agency, DOE possesses the talents and capabilities needed to realize the President's goals of halving carbon dioxide (CO_2) emissions by 2030, generating 100% clean electricity by 2035, and achieving net-zero emissions by 2050. These challenges call for new discoveries in the fundamental sciences, and BES's mission to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels has never been more relevant to our planet's future. BES is a crucial contributor to the DOE Science and Energy Technology Teams (SETTs) addressing the Hydrogen, Long Duration Energy Storage, and Carbon Negative Energy Earthshots. Breakthroughs are urgently needed to develop, implement, and scale the technologies necessary to reach these ambitious but achievable goals. Announcement of additional Earthshots is anticipated this year.

BES will play an important role in two new initiatives relayed in the fiscal year 2023 (FY23) President's Budget Request (PBR). The new Energy Earthshot Research Centers (EERCs) will assemble large, multi-disciplinary research teams to catalyze the scientific discoveries essential to realizing clean energy solutions. These cross-office teams will coordinate closely with the Energy Technology Offices, existing research, and demonstration projects and will be complemented by small group awards focused on bridging knowledge gaps. The new Accelerate Innovations in Emerging Technologies (ACCELERATE) initiative will support highly integrated research teams to expedite the discovery-to-commercialization process for new technologies to form the basis of future industries.

BES's user facilities were at the forefront of research efforts to combat the coronavirus pandemic (COVID-19) and will continue to support foundational research for energy technologies. Richmond will continue to ensure that BES facilities, operations, upgrades, and construction projects remain a priority to the nation's scientific leadership, especially in the face of intensifying overseas competition as found by BESAC's international benchmarking report.

Science is a human endeavor. The best and most creative innovation comes from intellectually and socially diverse teams. DOE's ability to address climate change and energy resilience will depend not only on basic research but also on dismantling barriers that have constrained science. The stewardship and promotion of a diverse and inclusive scientific workforce is foundational to DOE's mission and a top priority for Richmond. New SC initiatives like Reaching a New Energy Sciences Workforce (RENEW) will significantly expand training opportunities for undergraduate and graduate students from underrepresented and underserved groups and increase outreach activities to institutions historically underrepresented in the SC research portfolio. Younger generations want their science to have a true and lasting impact, surpassing simplistic publication and citation metrics. It is a new day at DOE, and all community members are called to take meaningful steps in advancing goals.

Discussion

Raising the international benchmarking report, **Kastner** called attention to U.S. retention of scientists, especially international individuals, at universities and national laboratories. **Richmond** said retention is at the forefront of her attention and that of the laboratories' leadership. Efforts are being made to expedite the retention salary-raise process at all national laboratories; the National Nuclear Security Administration (NNSA) has already done so. Universities face many challenges, and DOE is continuing to provide flexibility and support as it has throughout the pandemic. All BESAC members have influential positions, and now is the time to pay attention to student and workforce needs. DOE is supportive of international collaborative efforts across the agency, and SC released a memo enabling supplements to support Ukrainian scientists to collaborate at U.S. institutions or U.S. collaborators' institutions.

Ourmazd inquired about strengthening international collaborations. **Richmond** replied that SC and BES strongly recognize the importance of international collaboration but also see the need to balance with security. Determining how to keep science as open as possible to benefit from international collaborations is an ongoing focus and will take time.

Stack pointed to a divide between fundamental science and applications. How is DOE bridging this gap? **Richmond** is Under Secretary to both basic and applied offices; with the DOE reorganization, a portion of applied areas are focusing on deployment. This provides a unified umbrella for the continuous spectrum of basic research to applied technologies. SC's historical separation from applied areas is changing as cross-office and -program dialogue opens doors, including for the Earthshot initiatives. Though there may be debate about the role of the government in the innovation pipeline, SC is embracing the idea that basic research can be intensely use-inspired.

Friend asked how BESAC can be most helpful to the DOE's and Under Secretary's aspirations. **Richmond** stated that the advice provided in BESAC reports lends validity to the changes being pushed to those in leadership roles. It is important that BESAC communicate concerns or ideas, including those related to removing barriers and thinking more broadly about success. Emphasis on publication metrics may dissuade some from applied pursuits. The labs are already embracing this perspective. All must decide on more inclusive measurements of impact.

Office of Science Update, Steve Binkley, Office of Science Acting Director

Presentation cancelled.

Office of Basic Energy Sciences Update, Linda Horton, Associate Director; Bruce Garrett, Director, Chemical Sciences, Geosciences and Biosciences Division; and Andrew Schwartz, Director, Materials Sciences and Engineering Division

Horton shared information about new BES personnel, retirements, and vacancies. Andrew Schwartz is now the Materials Sciences and Engineering Division Director. Bruce Garrett, Chemical Sciences, Geosciences, and Biosciences Division Director, is retiring.

The Enacted FY22 BES Budget of ~$2.3B represents a 2.8% ($63M) increase over that of FY21. Research program funding increases by ~$117M and includes ~$696M for new and expanded investments in clean energy, manufacturing, microelectronics, and critical materials as well as funding for RENEW (at $3M), continuation of EPSCoR (Established Program to Stimulate Competitive Research, at $25M), and the new Biopreparedness Research Virtual

Environment (BRaVE) effort. BES will furnish BRaVE with critical analytical capabilities foundational to emergency responses. Furthermore, ~$119M is allocated for continuation of Computational Materials and Chemical Sciences, Energy Innovation Hubs, and the National Quantum Information Science Research Centers (NQISRCs). The Energy Frontier Research Centers' (EFRCs') budget increases by $15M to $130M. The Scientific User Facilities' budget increases by ~$16M, with $975M designated for operations at the 12 facilities to continue at 97% of the historically optimal level. Facilities Research receives $36M for artificial intelligence and machine learning (AI/ML) as well as Accelerator R&D in addition to $2M for RENEW. Funding for construction projects and major items of equipment (MIEs) decreases by $70M, with $106M for the Advanced Photon Source Upgrade (APS-U); ~$32M for the Linac Coherent Light Source-II (LCLS-II); $53M for the LCLS-II High Energy (LCLS-II-HE); ~$75M for the Advanced Light Source Upgrade (ALS-U); $17M for the Proton Power Upgrade (PPU); $32M for the Second Target Station (STS); $3M for the Cryomodule Repair and Maintenance Facility (CRMF); $15M for the Nanoscale Science Research Centers (NSRCs) Recapitalization; and $15M for the National Synchrotron Light Source II (NSLS-II) Experimental Tools (NEXT-II).

FY22 funding opportunity announcements (FOAs) include the Early Career Research Program (ECRP), with ~30 anticipated awards; Computational Chemical Sciences (CCS), with six to ten anticipated awards; Chemical and Materials Sciences to Advance Clean Energy Technologies and Low-Carbon Manufacturing (CEM), with proposals due May 17 and ~50 anticipated awards; EPSCoR, with proposals due April 14 and ~35 anticipated awards; and EFRCs, with proposals due May 3 and ~30-35 anticipated awards. Non-Carnegie Research 1 (Non-R1) Minority Serving Institutions (MSIs) will be the primary recipients of awards under a planned BES RENEW FOA. Awardees will form partnerships with and conduct internships at DOE laboratories or BES user facilities. RENEW will emphasize tracking of participant outcomes. Up to ten three-year awards are anticipated, totaling $5M in FY22 funds. Overall, there has been tremendous interest in clean energy research, and BES FY22 pre-applications have been five to ten times oversubscribed.

BES continues to participate in all of the Energy Earthshots, including co-leading the Hydrogen and Carbon Negative Shots.

BES held a Roundtable on Foundational Science for Carbon Dioxide Removal (CDR) Technologies in March 2022, to be reported on later in this meeting. A second Roundtable addressing Fundamental Science to Accelerate Nuclear Energy Innovation is being planned for July 2022.

The BES FY23 PBR of ~$2.42B is 4.9% (+$112M) greater than the FY22 Enacted Budget. Research priorities include the new SC Earthshot Initiative ($104M) which introduces the EERCs as a novel research modality bridging SC and the Energy Technology Offices. EERCs will be complemented by small group awards. RENEW and EPSCoR funding increases by $5M and $10M, respectively. The FY23 EPSCoR program will focus on larger-team implementation awards facilitating research infrastructure development. The new Funding to Accelerate Inclusive Research (FAIR, $20M) effort will complement RENEW by building relationships between MSIs and the DOE national laboratories and facilities to enhance research on clean energy and related topics at MSIs. Activities will improve the infrastructure, capacity, capability, and expertise of MSIs to perform and propose competitive research. BES will also participate in the new Accelerate Innovations in Emerging Technologies (ACCELERATE, $15M) initiative to accelerate the transition of science advances to clean energy technologies, including future-generation microelectronics, low-carbon manufacturing, and emerging

technologies to move from laboratory to industrial prototypes. BRaVE and AI/ML funding increase by $9M each, while support continues for the Quantum Information Science (QIS), NQISRCs, EFRCs, Fuels from Sunlight and Batteries and Energy Storage Energy Innovation Hub Programs, Manufacturing and Microelectronics, and Computational Chemical and Materials Sciences. The Batteries Hub Program will be openly recompeted in FY23. User facilities will operate at ~90% of optimal, and BES will continue support for major facility upgrades (+$12M).

FY22 commissioning activities and upgrades for construction projects and MIEs have continued. LCLS-II was re-baselined in 2020 with a new total project cost (TPC) of $1.136B. No FY23 funding is required, and Critical Decision-4 (CD-4) is projected for FY24. APS-U received CD-3 in 2019; dark time for installation is projected to begin in FY23, and CD-4 is projected for FY26. PPU, which will double the Spallation Neutron Source (SNS) accelerator beam power to 2.8 MW, received CD-2/3 in 2020; CD-4 is projected for FY28. ALS-U attained CD-2 in 2021 with CD-3 projected for FY23 and CD-4 for FY29. LCLS-II-HE resides at CD-1/3A. Pandemic-related delays and cost contingencies could impact the current $660M TPC estimate. CD-2/3 is planned for FY23 with CD-4 in FY31. The STS is at CD-1; the TPC is $1.8B-$3.0B, with a preliminary point estimate of ~$2.2B. CD-2/3 is projected for FY25, and CD-4 projected for FY37. The CRMF resides at CD-0 with a TPC ranging from $70M to $98M and a preliminary point estimate of $94M. CD-1/3A is projected for FY23. The NEXT-II MIE resides at CD-2/3, which was awarded in October 2021, with a TPC of ~$95M. CD-4 is projected for FY28. The NSRC Recapitalization MIE was awarded CD-2/3 in March 2022 and has a TPC of $80M. CD-4 is projected for FY28. FY23 Other Project Cost funds will also initiate plans for the High Flux Isotope Reactor (HFIR) Pressure Vessel Replacement and NEXT-III, which will build out additional beamlines for NSLS-II.

Discussion

Horton led BESAC and attendees in thanking Garrett for his service.

Hellman posed questions about the ECRP. **Horton** indicated that ~30 awards are issued annually to universities and national laboratories, and conferral depends on application quality. BES investment in ECRP has been relatively stable. However, if appropriations are low, programs, including the ECRP, are broadly impacted. Unlike at universities where ECRP awards can launch work in new areas for the university, laboratory awards are examined for consistency with ongoing laboratory strengths. Following advice from BES's Committee of Visitors (COV), annual BES ECRP FOAs now alternate between award topics on a biennial basis; halving available topical areas in any given year has been important for improving the applicant success rate from <1% to ~5%.

Bent asked about revitalizing graduate fellowship programs. **Horton** explained that Congress decided SC's earlier graduate fellowship program fell within the National Science Foundation (NSF) mission space. BES participates in the current SC-wide Graduate Student Research (SCGSR) Program that provides funds for three to twelve month opportunities for graduate students to work at national laboratories as part of the research they are conducting for their faculty advisors. This program has taken on a virtual aspect due to COVID-19, which may help mitigate program criticisms of pulling students away from their core research groups. The program focuses on topical areas where BES has a stewardship role. **Schwartz** added that BES tends to have the largest number of SC graduate fellowship awardees; this is a significant program. Direct engagement of students is important, and hopefully programs can soon be

conducted in person. The community is encouraged to share information about DOE and/or BES programs.

MacDonald sought perspectives on the effectiveness and importance of single-investigator programs relative to other funding modalities. **Horton** stated that single-investigator funding is critical for innovative research; single principal investigators (PIs) are a foundation for out-of-the box ideas. **Garrett** said CEM requires universities to submit at least one single-PI application out of the three permitted. Many awardees of BES's Open FOA are also single PIs.

Gibson approved of RENEW and FAIR, and asked about MSI eligibility for RENEW. These programs may increase participation of Historically Black Colleges and Universities (HBCUs), Tribal Colleges and Universities (TCUs), and other institutions. **Horton** confirmed RENEW is open to non-R1 MSIs. RENEW and FAIR are subsets of BES's outreach. BES program selection factors consider institutional diversity.

Archer commented that undergraduate research is a gateway to graduate school. Current NSF PIs can often apply for supplemental funds to support summer undergraduate research. Is DOE considering mechanisms beyond graduate fellowships to promote undergraduate research? The community could express to representatives that DOE plays an important and differentiated role from NSF in educating science-based materials researchers. Also, what role did industry play in setting Earthshot targets? **Horton** appreciated the recommendation to provide supplemental undergraduate research awards. BES does support undergraduate cadres through team funding modalities and RENEW incorporates undergraduate support elements. The DOE technology programs have robust industry connections, and industry perspectives were critical to setting credible stretch goals. Industry perspectives are also sought and engaged in BES roundtables and Basic Research Needs (BRN) workshops.

Dosch complimented programmatic foresight. Is there close cooperation between BRaVE and medical agencies like the National Institutes of Health (NIH)? **Horton** relayed strong multi-agency activities, some of which had international dimensions, evolved from the COVID-19 response, especially in data sharing. The national laboratories leveraged close industry ties and Congressional funds to support the pandemic response, such as collaborating with Coca-Cola in making viral test kits. The Nanoscience Centers were engaged in rapid manufacturing techniques and product quality assessments. Regional laboratory engagement was crucial, given supply chain issues. BES is broadly engaged with NIH to ensure that BES user facilities are leveraged for pandemic responses and cancer diagnostics and treatments. BES is endeavoring to expand such interactions. **Schwartz** said forums such as the National Nanotechnology Initiative interagency committee foster cross-agency dialogue.

Friend dismissed the meeting at 1:07 pm for a break and reconvened the meeting at 1:30 pm.

JCESR: Scientific Progress and Technological Impact, George Crabtree, Argonne National Laboratory and University of Illinois at Chicago

Founded in 2012, the Joint Center for Energy Storage Research (JCESR) initially focused on development of a single low-cost, high-energy density, beyond lithium-ion (Li-ion) battery for electric vehicles and electricity grids provisioning five times the then-current energy density at one fifth of the then-current cost. During its first five years, JCESR made extensive use of computational simulation before materials synthesis, and multimodal characterization. Fundamental science outcomes included technoeconomic modeling, comprehensive simulation of multivalent cathodes and solid-state electrolytes, anode stripping and plating in multivalent

electrolytes, introduction and rational design of redoxmers, polymer inclusion membranes (PIMs) for size and charge separation, and Li-sulfur (Li-S) lean electrolytes and alternate reaction pathways. JCESR conducted four laboratory demonstrations and generated three startup companies.

JCESR's funding was renewed for an additional five years in 2018 to build batteries using transformative materials, chemistries, and architectures. Employing a bottom-up approach that leverages AI/ML for materials discovery, JCESR predicts electrochemical phenomena at atomic and molecular levels to meet targeted battery performance metrics with results serving all next-generation batteries and applications. The Center's primary milestones address solvation at atomic and molecular levels, redoxmer design that satisfies multiple performance metrics simultaneously, and multivalent ion materials design. Science highlights from the last milestone include new high-voltage cathodes and electrolytes for calcium-ion (Ca-ion) batteries.

JCESR collaborates with ~60 U.S. universities, ~25 European Union (E.U.) universities, DOE laboratories, BES user facilities, and industry. The Center currently engages ~180 researchers, including graduate students, postdoctoral scholars, and senior scientists. Of JCESR's ~230 alumni, 41% work in diverse industries, 44% in academia, and 13% at national laboratories. From its launch, JCESR has produced 774 publications in peer-reviewed journals, 82 invention disclosures, and 57 active patents. JCESR has also led and hosted a wide spectrum of outreach activities, including mentorship events, conference organization, scientific workshops, and industry outreach to engage with the energy storage ecosystem. Form Energy, one of seven JCESR startups, is currently partnering with Great River Energy and Georgia Power to deliver iron-oxygen (Fe-O) batteries for long-duration energy storage at large scale.

Discussion

Friend observed Ca could increase battery weight, but Ca may be more abundant than Li. **Crabtree** said zinc, Mg and Ca are heavier than Li but form divalent cations, yielding two electrons per reaction. If the theoretical capacity is attained, higher-density batteries still result. Additionally, these elements are 1000x times more abundant in the earth's crust than Li. Cathodes for these multivalent batteries do not use nickel or cobalt, circumventing international supply chain issues and enabling battery manufacture anywhere. The body of publications addressing multivalent batteries has been growing rapidly over the last five years.

Plant Research Laboratory: Photosynthetic Energy Capture, Conversion, and Storage: From Fundamental Mechanisms to Modular Engineering, Christoph Benning, Michigan State University

The Plant Research Laboratory (PRL) was founded in 1964 through a contract between the Atomic Energy Commission (AEC), DOE's predecessor, and Michigan State University (MSU). PRL's purpose is "… to conduct a comprehensive, interdisciplinary research and related education and training program in plant sciences with the principal emphasis being the development of an understanding of how higher plants function as whole organisms, both as individuals and as populations in an environment …". Based at MSU, PRL currently comprises 12 faculty collaborating on three subprojects: 1) Primary capture, storage, and regulation of light energy; 2) Integrating energy supply and demand in the biological solar panel; and 3) Characterization and engineering of modules for photosynthetic productivity. Expected outcomes are the exploration of photosynthetic processes at multiple scales, a comprehensive understanding of real-life photosynthesis, and the investigation of basic mechanisms of energy

storage by oxygenic photosynthesis. Gained knowledge will improve photosynthetic efficiency and plant productivity, plant resilience to climate change, and development of combinable photosynthetic modules for photosynthesis-based bioproducts. Research project highlights addressed 1) the function of thylakoid lipids in photosynthesis under dynamic conditions; 2) a cyanobacterial model to study the effect of carbon partitioning on photosynthetic performance; and 3) self-assembling protein architectures for plant synthetic biology.

Discussion

Garcia inquired about scaling plant robustness to higher CO_2 levels. **Benning** remarked that PRL is focused on the fundamentals of how plants work; the next step is translation. Scaling occurs at the agricultural level. Creative approaches are under consideration, such as modifying rice in paddies and adding algae that can be harvested separately. Trying to scale algal bioreactors will not work. Other ideas include self-healing concrete or using plants to produce carbon nanotubes. Success arises from diverse experts working together.

Roundtable on Foundational Science for Carbon Dioxide Removal Technologies, Krista Walton, Georgia Institute of Technology

Held in March 2022, the virtual Roundtable on Foundational Science for Carbon Dioxide Removal Technologies was organized by BES (lead), the Office of Fossil Energy and Carbon Management (FECM), the Office of Energy Efficiency and Renewable Energy (EERE), and Advanced Research Projects Agency-Energy (ARPA-E), with the goal of identifying the key underpinning science needs and priority research opportunities (PROs) that will accelerate research, development, and deployment of CDR technologies. The Roundtable engaged ~30 participants from national laboratories, universities, industry, and other stakeholders in considering areas for BES research to enable and advance CDR technologies to capture CO_2 from dilute sources, durably store CO_2 in minerals and materials, or geologically sequester CO_2. CDR (direct atmospheric capture and storage) technologies are necessary to offset hard-to-avoid emissions; realizing effective technologies is critical to achieving the Carbon Negative Earthshot, the President's goal of a net-zero carbon economy by 2050 and removing legacy carbon pollution in a just and sustainable manner. Notably, CDR is distinct from point-source carbon capture from the fossil power sector and heavy-duty industry.

The Roundtable drew on BES's 2010 and NAS's 2019 reports, respectively, entitled *Basic Research Needs for Carbon Capture: Beyond 2020* and *Negative Emissions Technologies and Reliable Sequestration*. Discussions yielded five PROs: 1) Master interfacial processes of CO_2 transport and reactivity across multiple length and time scales; 2) Design and synthesize materials that simultaneously achieve multiple functions for CO_2 capture and conversion; 3) Discover unconventional pathways and materials for energy-efficient CO_2 capture, release, and conversion; 4) Control multiphase interactions required for CO_2 conversion into molecules, minerals, and materials; and 5) Achieve predictive understanding of complex subsurface geologic processes to enable secure carbon storage. A brochure summarizing Roundtable outcomes will be released in May 2022. Final report delivery is targeted for late summer.

Discussion

Stack asked about CO_2 conversion into useful, durable, and in-demand items. Surface sequestration of any solid-phase product would remove the need for injection wells. **Walton** indicated panel discussions focused on basic science, not market factors. These are important questions. **Garrett** explained CDR is not necessarily focused on useful products, but in locking

carbon up for a long time through processes like mineralization. Injecting CO_2 into the ground is costly and wells must be monitored.

Epps inquired about sequestering carbon in biomass or plastics. **Walton** was unsure if such specific systems were considered. The Conversion PRO may have addressed this topic in its examination of nucleation, growth, and dissolution of solid phases. Discussions generally centered on upstream processes such as active sites, confinement, or mass transport as well as multi-modal, cross-scale approaches to promote effective chemical transformations. **Garrett** observed that the DOE Bioenergy Technologies Office (BETO) is pursuing Bioenergy with Carbon Capture and Storage (BECCS) approaches. BECCS is viable and important but was not in scope of the CDR Roundtable, which focused on topics identified by NAS as less explored.

Chen remarked that direct air capture of CO_2 sounds difficult compared to source capture; are there effectiveness statistics? **Walton** advised that CDR technologies are distinct from point-source capture and are not meant to be a blanket solution. Until now, point-source capture has been a primary focus, but the Roundtable's purpose was to address ambient removal technologies that have received less attention. **Garrett** noted that statistics may be available at cdrprimer.org. There are many sectors where source capture is very difficult.

Friend dismissed the meeting at 3:00 pm for a break and reconvened the meeting at 3:30 pm.

Scientific Competitiveness: Challenges in Diversity, Equity, Inclusion, and Workforce Retention, Panel Lead: Matthew Tirrell, University of Chicago and Argonne National Laboratory

BESAC's international benchmarking report titled *Can the U.S. Compete in Basic Energy Sciences? Critical Research Frontiers & Strategies* found China is surging in critical areas, Europe leads in QIS, and the U.S.'s own trajectory is flattening or falling behind. Strategies for success include increased investment in research, facilities, and instrumentation; greater support for early- and mid-career scientists; opportunities for facility staff scientists; and integration of energy sciences research across the basic-to-applied-to-industrial spectrum.

The State of U.S. Science & Engineering, Vipin Aurora and Amy Burke, National Science Foundation

The National Center for Science and Engineering Statistics (NCSES), NSF's statistical agency, produces the Science and Engineering (S&E) Indicators report for the National Science Board (NSB). This congressionally mandated, biennial report addresses research, development, and innovation as well as S&E education and workforce statistics. Key takeaways from the 2022 report are: 1) The U.S. is a global leader across different aspects of S&E and has a central role as an international collaborator; 2) The U.S.'s position and role are changing as other countries grow their science and technology (S&T) investments and capabilities at a faster rate; 3) New measures of the STEM workforce illustrate the importance of skilled technical workers; 4) There is an uneven distribution of S&E activities and STEM career opportunities across our country; and 5) Foreign-born workers are a large segment of the S&E workforce.

Highlighted findings addressed U.S. STEM workforce composition broken down by educational level and occupation and/or by race, ethnicity, and gender. The report found 23% of the entire U.S. workforce, corresponding to 36M individuals, is engaged in STEM jobs. Geographic statistics examined the distribution of the STEM workforce and select Knowledge

and Technology Intensive Industries. Educational statistics show the intersection of STEM teacher experience and the socioeconomic and demographic composition of schools as well as student math scores by ethnicity and/or race. R&D indicators address U.S. spending and R&D-intensive output over time and across different sectors. U.S. R&D indicators were contextualized in the global arena and compared to that of China, the E.U., and other selected countries. Finally, U.S. S&E publication statistics were presented compared to those of other world leaders. A global collaboration network of COVID-19 publications was highlighted.

Discussion

Tirrell asked about STEM labor definitions. **Burke** clarified S&E occupations as those in computer sciences, social sciences, physical sciences, life and biological sciences, and engineering. S&E-Related positions primarily include healthcare workers. Those in Middle Skill occupations, also referred to as the skilled technical workforce, require significant technological expertise and scientific and engineering knowledge, but do not necessarily have a bachelor's degree. Examples include manufacturing, installation, maintenance, and repair jobs. STEM worker categories were derived from a Bureau of Labor Statistics skills-based data set.

Takeuchi asked if the STEM workforce definition included teachers. **Burke** confirmed. NCSES collects data separating post-secondary education from primary and secondary education. Post-secondary STEM teachers are more often involved in R&D and innovative occupations, while primary and secondary teachers are generally considered S&E-Related.

Stack inquired how the 23% percent of the U.S. workforce engaged in STEM jobs compares to that of other countries. **Burke** said data for international comparisons is lacking.

Horton commented that no states with a high concentration of a skilled technical workforce appear to also have a high concentration of S&E or S&E-Related workers. **Arora** confirmed.

Meng asked if students self-identified their races and ethnicities for the math scores dataset. Are R&D spending data by country presented as absolute values or normalized per capita? **Burke** stated that more than one race means mixed race. Data were obtained from the National Assessment of Educational Progress (NAEP). **Arora** shared that R&D spending values are absolute numbers and not adjusted for inflation; nominal expenditures are the international standard.

Gibson posed a question about total European R&D expenditures. **Burke** said the E.U.'s worldwide share in expenditures is ~20%.

Epps suggested tracking R&D expenditure growth rates as opposed to total dollars. **Arora** articulated that the report tracks growth rates, and it is important to consider growth rates over different time periods. Nominal expenditures is a standard benchmark monitored by the NSB. **Burke** noted that China contributed 29% to the growth in worldwide R&D expenditures, while the U.S. and E.U.-27 (following Brexit) contributed 23% and 17%, respectively.

Tirrell commented that U.S. R&D expenditures doubled from 2000 to 2019 while China's increased by over an order of magnitude because their funding levels were initially low. **Arora** added that the Chinese growth rate has also been faster.

Chen asked about segregating administrative costs from R&D spending. **Arora** relayed that this has been a long-standing challenge; separating R&D inflationary costs from all other inflationary aspects is difficult. An index to deflate nominal expenditures is lacking.

Friend expressed curiosity about China's R&D expenditures in Basic Research versus other sectors. **Arora** advised that data from ~4 years ago indicated more of China's funding was dedicated to Experimental Development than Basic Research.

Bent pivoted to segregating business R&D statistics. **Arora** explained that U.S. data can be disaggregated, but country comparisons are problematic due to reporting aggregation at the Organisation for Economic Co-operation and Development (OECD) level.

SC Diversity, Equity & Inclusion Initiatives and BES Activities Update, Julie Carruthers, Office of Scientific Workforce Diversity, Equity, and Inclusion, and Gail McLean, Office of Basic Energy Sciences

SC is well positioned to address the forthcoming DOE response to the January 2021 Executive Order on *Advancing Racial Equity and Support for Underserved Communities through the Federal Government.* A new SC Diversity, Equity and Inclusion (DEI) working group is taking a phased approach to enacting >40 recommendations submitted in a 2020 report evaluating all aspects of SC's activities for DEI. Before being approved by leadership and broadly deployed, new SC guidance is being pilot-tested and refined via focus groups. A subset of ongoing activities include the required incorporation of diversity-promoting policy factors and review criteria in all FOAs and S&T performance reviews; visibility of existing flexibilities and support allowed under financial assistance agreements; standard SC FOA language to communicate existing regulations/requirements regarding non-discrimination and personal conduct; actions to increase response rates of applicants and reviewers to the demographics questions in the Portfolio Analysis Management System; uniform guidance for all SC-sponsored workshops and roundtables as well as SC FACA subcommittees to promote diverse participation and inclusive behaviors.

Over the last six years, DOE SC has reformulated DEI approaches at national laboratories from being primarily compliance-based to action- and strategy-driven. Laboratories were required to develop strategic DEI plans and post workforce demographics online. SC synthesized best practices into a summary report and decoupled annual DEI feedback from the annual laboratory strategic planning process. In 2019, SC conducted its first external peer review of the SC laboratories' DEI strategies, and the 2020 Performance Evaluation and Measurement Plan process required laboratories to deliver plans to address their weaknesses. SC is revisiting laboratory performance plan requirements in 2022 to create greater emphasis on DEI actions that will go into effect in FY23. SC will continue to annually update the best practices report for laboratories and evaluate progress of laboratories on a rotating basis.

Beginning in 2020, SC also launched a coordinated approach to increase participation of historically underrepresented individuals and institutions. A series of listening sessions held in 2021 highlighted systemic barriers, lack of awareness of opportunities, implicit bias, solicitation processes, and access to equipment as impediments to participation. Additional comments addressed recruitment, promoting DEI, and mentoring. Listening session input is informing SC's approaches to the RENEW initiative.

BES participated in SC listening sessions to understand and address challenges faced by MSIs and underrepresented groups (URGs). BES FOAs now incorporate language encouraging applications from MSIs, including HBCUs, as well as individuals from historically URGs. BES

is hosting webinars to increase awareness of FOAs and expanding use of email distribution lists to communicate opportunities. The new FAIR and RENEW initiatives build on listening session feedback and best EPSCoR practices, and BES is seeking additional ways to engage URGs and MSIs in SC-sponsored research funding or in opportunities at laboratories and user facilities. BES is also more broadly advertising open positions. Comments regarding DEI activities from PIs and the community are welcomed.

Discussion

Stack expressed appreciation for the SC's DEI website.

Tirrell appreciated DEI efforts. Data collection will enable progress evaluation.

Friend inquired about identification of and actions to address specific gaps such as lack of PI grant writing experience or institutional grants management infrastructure. **McLean** said there are ongoing, internal discussions on how to improve guidance on grants management and proposal submission for institutions not used to applying for DOE funding opportunities. **Horton** relayed that the EFRCs have developed an early career network (ECN) with activities including grant writing and other topics relevant to the community. Activities have had tremendous community participation as well as support from programs other than BES. There are opportunities to expand this work. Before COVID-19 made virtual meetings common, BES held virtual question and answer sessions as well as seminars to support EPSCoR states. Although the FY22 appropriation was just received, BES is not rushing the RENEW process since grants offices at first-time institutions will need additional time to navigate the application procedure. **Stack** (chat) observed that there is a writing webinar next week through the EFRC ECN.

Epps suggested providing seminars or workshops to target institutions to explain the value of DOE grants and how they can affect faculty and students. Faculty may be interested in pursuing grants, but support may be absent at the administrative level in both ideology [focus of the institutions on teaching] and provision of personnel [support for research administration]. **Horton** appreciated this feedback, which also arose in some of the DOE's listening sessions. Broader outreach may be appropriate.

Gibson echoed and agreed with earlier comments. Teaching loads at target institutions present an additional challenge that is beyond the DOE's ability to address. However, there is an opportunity for coordinated investments in MSIs at the interagency level, including with the Department of Education.

Public Comments

Horton discussed venues and the timeline for future meetings.

Henrique De Paoli (LBNL, chat) asked about potential initiatives in living materials and co-work with the Office of Biological and Environmental Research (BER). Currently, BES has focused on biomimicry and BER on biodesign. **Garrett** explained that BES and BER both conduct fundamental but complementary research in the living materials space. BES takes a bottom-up approach, examining molecular mechanisms behind metabolic pathways. BER employs the top-down approaches of systems biology and genomics to manipulate similar systems and extract biological information. Work across both programs couples well in some areas like catalysis. BES is probably the only program focused on fundamental mechanisms of

photosynthesis. **McLean** noted that BER held a biomaterials workshop a few years ago. The report is available online. **Horton** elaborated that the workshop focused on genomics materials design, which is not a BES activity. BES, BER, and the Office of Advanced Scientific Computing Research (ASCR) are collaborating on the Hydrogen and Carbon Negative Earthshots and EERCs. One of the NQISRCs is studying sensors relevant to BER, and the Center has both BES and BER support. BER also supports BES user facilities; light and neutron sources deliver on BER program needs.

Albert Moussa (BlazeTech, chat) voiced concerns about engineering schools encouraging entrepreneurship and recent U.S. engineering bachelor's graduates flocking to startups. Undergraduates have a romantic view of startups. Has this gone too far in adversely impacting basic sciences graduate work? The U.S. risks falling behind. **Friend** remarked this is an interesting question but one without data to provide an answer. **Horton** speculated that NSF may have data. Perhaps there are opportunities to encourage those from industry to return to basic sciences. **Meng** indicated that some domestic students return for graduate work after startup experience because they realize the importance of advanced training. More data on this should be collected.

James Mitchell (University of Oregon, chat): sought recommendations for BES and other DOE career options for young scientists following a postdoc. **Schwartz** recommended seeking advice from as many people as possible. The BES ECN provides webinars and networking opportunities. Members are primarily graduate and postdoctoral students. Planned webinars include those addressing career paths in academia and industry. **Horton** relayed that the majority of BES staff have PhDs and subsequent research experience. Programs offering post-degree internships, especially the American Association for the Advancement of Science (AAAS), offer good experiences. Many SC and BES staff, including Robin Hayes who leads the ECN, are former AAAS fellows. **Friend** mentioned the Civic Science Fellows program.

Friend thanked BESAC members and attendees and adjourned the meeting at 5:00 p.m.

Respectfully submitted on April 26, 2022
Holly Holt, PhD
Science Writer
Oak Ridge Institute for Science and Education and Oak Ridge Associated Universities