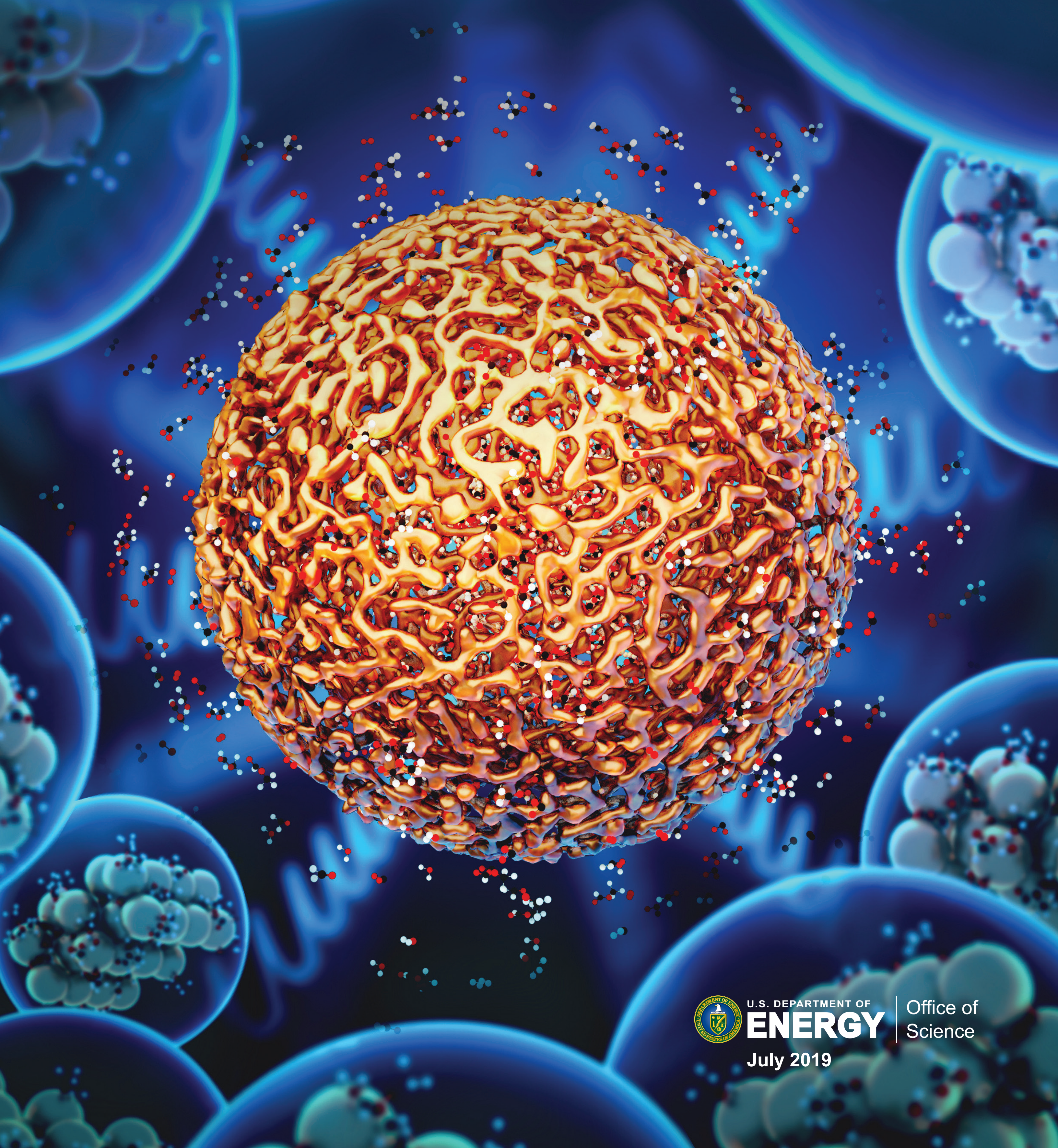
ENERGY FRONTIER RESEARCH CENTERS

SCIENCE FOR OUR NATION'S ENERGY FUTURE



U.S. DEPARTMENT OF ENERGY | Office of Science

July 2019

46 CURRENT EFRCs

CALIFORNIA

Center for Novel Pathways to Quantum Coherence in Materials (NPQC)
Lawrence Berkeley National Laboratory

Center for Mechanistic Control of Water-Hydrocarbon-Rock Interactions in Unconventional and Tight Oil Formations (CMC-UF)
Stanford University

Photonics at Thermodynamic Limits (PTL)
Stanford University

Center for Gas Separations (CGS)
University of California, Berkeley

Center for Synthetic Control Across Length-Scales for Advancing Rechargeables (SCALAR)
University of California, Los Angeles

Spins and Heat in Nanoscale Electronic Systems (SHINES)
University of California, Riverside

Quantum Materials for Energy Efficient Neuromorphic Computing (Q-MEEN-C)
University of California, San Diego

COLORADO

Center for Hybrid Organic Inorganic Semiconductors for Energy (CHOISE)
National Renewable Energy Laboratory

Center for Next Generation of Materials Design (CNGMD)
National Renewable Energy Laboratory

DELAWARE

Catalysis Center for Energy Innovation (CCEI)
University of Delaware

FLORIDA

Center for Actinide Science & Technology (CAST)
Florida State University

Center for Molecular Magnetic Quantum Materials (M^2QM)
University of Florida

GEORGIA

Center for Understanding and Control of Acid Gas-Induced Evolution of Materials for Energy (UNCAGE-ME)
Georgia Institute of Technology

IDAHO

Center for Thermal Energy Transport under Irradiation (TETI)
Idaho National Laboratory

ILLINOIS

Advanced Materials for Energy-Water Systems (AMEWS)
Argonne National Laboratory

Center for Electrochemical Energy Science (CEES)
Argonne National Laboratory

Center for Bio-Inspired Energy Science (CBES)
Northwestern University

Center for Light Energy Activated Redox Processes (LEAP)
Northwestern University

IOWA

Center for the Advancement of Topological Semimetals (CATS)
Ames Laboratory

MARYLAND

Institute for Quantum Matter (IQM)
Johns Hopkins University

Nanostructures for Electrical Energy Storage (NEES)
University of Maryland

MASSACHUSETTS

Integrated Mesoscale Architectures For Sustainable Catalysis (IMASC)
Harvard University

Center for Enhanced Nanofluidic Transport (CENT)
Massachusetts Institute of Technology

MINNESOTA

Inorganometallic Catalyst Design Center (ICDC)
University of Minnesota

NEW JERSEY

Bioinspired Light-Escalated Chemistry (BioLEC)
Princeton University

NEW MEXICO

Fundamental Understanding of Transport Under Reactor Extremes (FUTURE)
Los Alamos National Laboratory

NEW YORK

NorthEast Center for Chemical Energy Storage (NECCES)
Binghamton University

Molten Salts in Extreme Environments (MSEE)
Brookhaven National Laboratory

Programmable Quantum Materials (Pro-QM)
Columbia University

Center for Alkaline-Based Energy Solutions (CABES)
Cornell University

A Next Generation Synthesis Center (GENESIS)
Stony Brook University

Center for Mesoscale Transport Properties (m2M/t)
Stony Brook University

NORTH CAROLINA

Alliance for Molecular PhotoElectrode Design for Solar Fuels (AMPED)
University of North Carolina at Chapel Hill

OHIO

Breakthrough Electrolytes for Energy Storage (BEES)
Case Western Reserve University

Center for Performance and Design of Nuclear Waste Forms and Containers (WastePD)
Ohio State University

PENNSYLVANIA

Center for Lignocellulose Structure and Formation (CLSF)
Pennsylvania State University

Center for Complex Materials from First Principles (CCM)
Temple University

SOUTH CAROLINA

Center for Hierarchical Waste Form Materials (CHWM)
University of South Carolina

TENNESSEE

Energy Dissipation to Defect Evolution (EDDE)
Oak Ridge National Laboratory

Fluid Interface Reactions, Structures and Transport Center (FIRST)
Oak Ridge National Laboratory

TEXAS

Center for Materials for Water and Energy Systems (M-WET)
University of Texas at Austin

UTAH

Multi-Scale Fluid-Solid Interactions in Architected and Natural Materials (MUSE)
University of Utah

WASHINGTON

Center for Molecular Electrocatalysis (CME)
Pacific Northwest National Laboratory

Interfacial Dynamics in Radioactive Environments and Materials (IDREAM)
Pacific Northwest National Laboratory

Center for the Science of Synthesis Across Scales (CSSAS)
University of Washington

Biological Electron Transfer and Catalysis Center (BETCy)
Washington State University

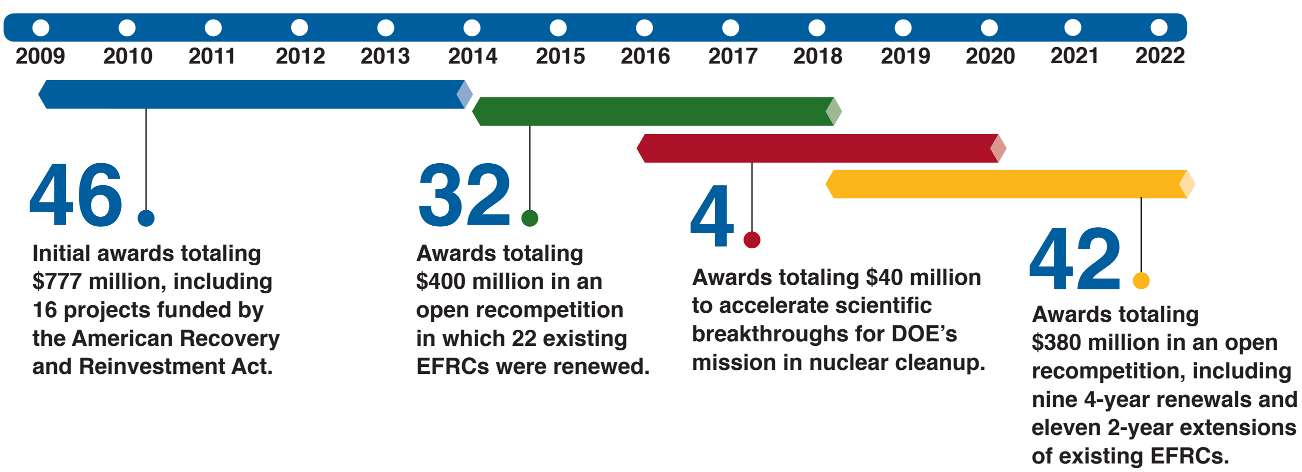
For more information:
science.osti.gov/bes/efrc

ENERGY FRONTIER RESEARCH CENTERS
SCIENCE FOR OUR NATION'S ENERGY FUTURE

As world demand for energy rapidly expands, transforming the way energy is collected, stored, and used has become a defining challenge of the 21st century. At its heart, this challenge is a scientific one, inspiring the U.S. Department of Energy's (DOE) Office of Basic Energy Sciences (BES) to establish the Energy Frontier Research Center (EFRC) program in 2009. The EFRCs represent a unique approach, bringing together creative, multidisciplinary scientific teams to perform energy-relevant basic research with a complexity beyond the scope of single-investigator projects. These centers take full advantage of powerful new tools for characterizing, understanding, modeling, and manipulating matter from atomic to macroscopic length scales. They also train the next-generation scientific workforce by attracting talented students and postdoctoral researchers interested in energy science.

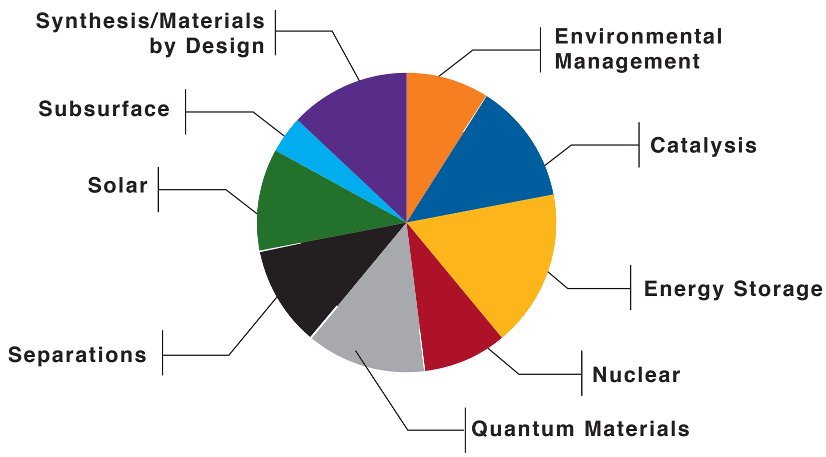
To date, BES has supported 82 EFRCs, of which 46 are currently active, involving more than 1,600 senior investigators and at least 5,400 students and postdoctoral researchers at over 170 institutions. The EFRCs have collectively demonstrated the potential to substantially advance the scientific understanding underpinning transformational energy technologies. Both a BES Committee of Visitors and a Secretary of Energy Advisory Board Task Force have found the EFRC program to be highly successful in meeting its goals. The scientific output from the EFRCs is impressive, and many centers have reported that their results are already impacting both technology research and industry. This report on the EFRC program includes selected highlights from 2016-2019.

EFRC AWARDS HISTORY



The EFRCs are large team efforts as shown here from the all hands meeting for the Center for Synthetic Control Across Length Scales for Advancing Rechargeables (SCALAR). Each EFRC holds an annual meeting with its team of researchers and advisory board members to review and plan research activities. Combined, the current EFRCs have more than 260 scientific advisory board members from 13 countries and 27 companies.

EFRC TOPICAL AREAS



DISTRIBUTION OF CURRENT EFRCs

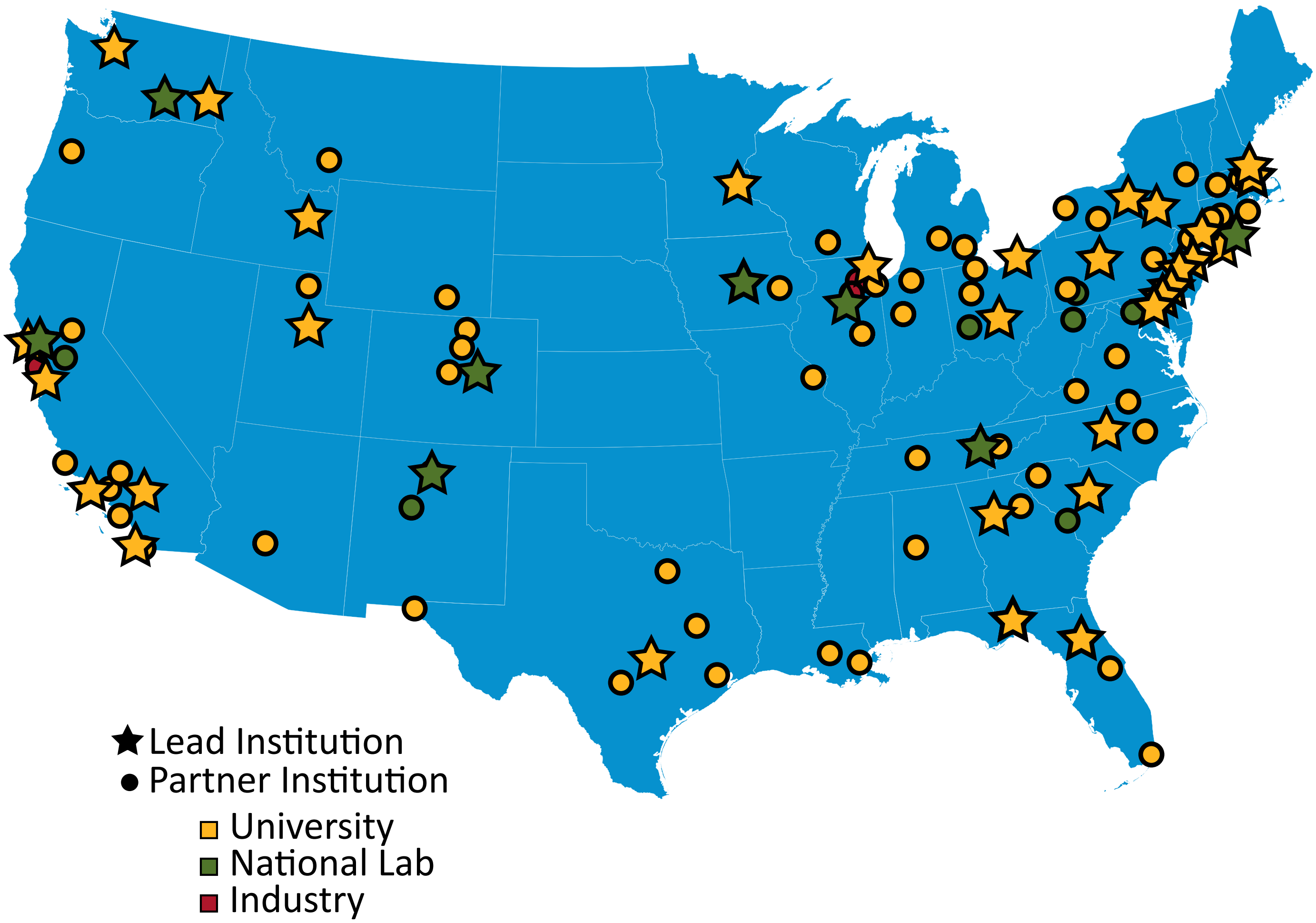
EFRC awards span the full range of energy research challenges, as depicted in the chart above. The scientific community identified these and other challenges in a series of BES workshop reports that describe basic research for advancing technologies to support Department of Energy missions in energy, environment, and national security. Workshop topics included solar energy utilization, next-generation electrical energy storage, carbon capture and sequestration, future nuclear energy, catalysis science, hydrogen science, solid-state lighting, quantum materials, synthesis science, energy and water, transformative experimental tools, and environmental management. The EFRCs also address scientific grand challenges described in the reports *Directing Matter and Energy: Five Challenges for Science and the Imagination* and *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*. These community workshops have been held since the early 2000s, with thousands of participants identifying "basic research needs" for energy applications and "grand-challenge science." These workshops form the foundation for the EFRC program.

WORKSHOP REPORTS

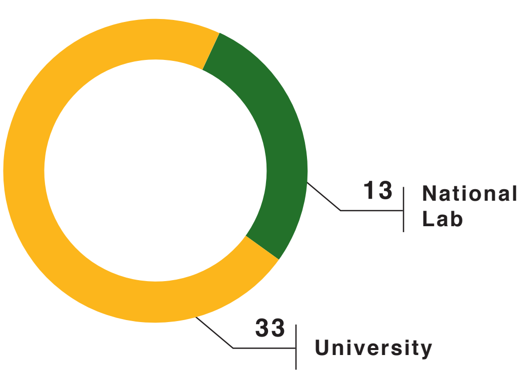
For more information: science.osti.gov/bes/community-resources/reports

CURRENT EFRCs

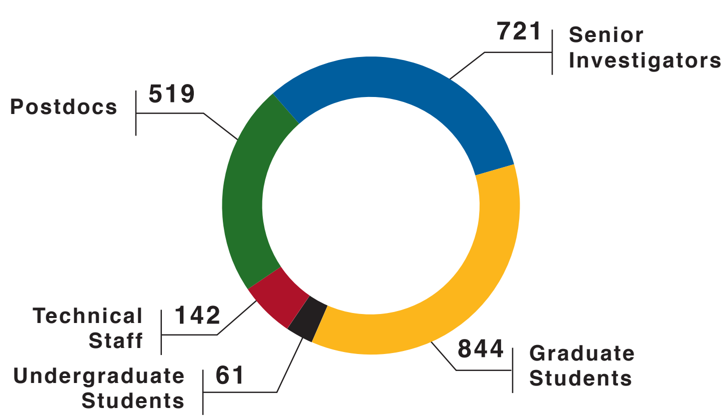
The EFRCs are integrated, multi-investigator partnerships among universities, national laboratories, and for-profit firms to conduct fundamental research focusing on one or more “grand challenges” and use-inspired “basic research needs” identified by the scientific community in a series of BES workshop reports. The 46 EFRCs involve over 115 unique institutions through 310 partnerships in 36 states and 4 foreign countries.



LEAD INSTITUTIONS

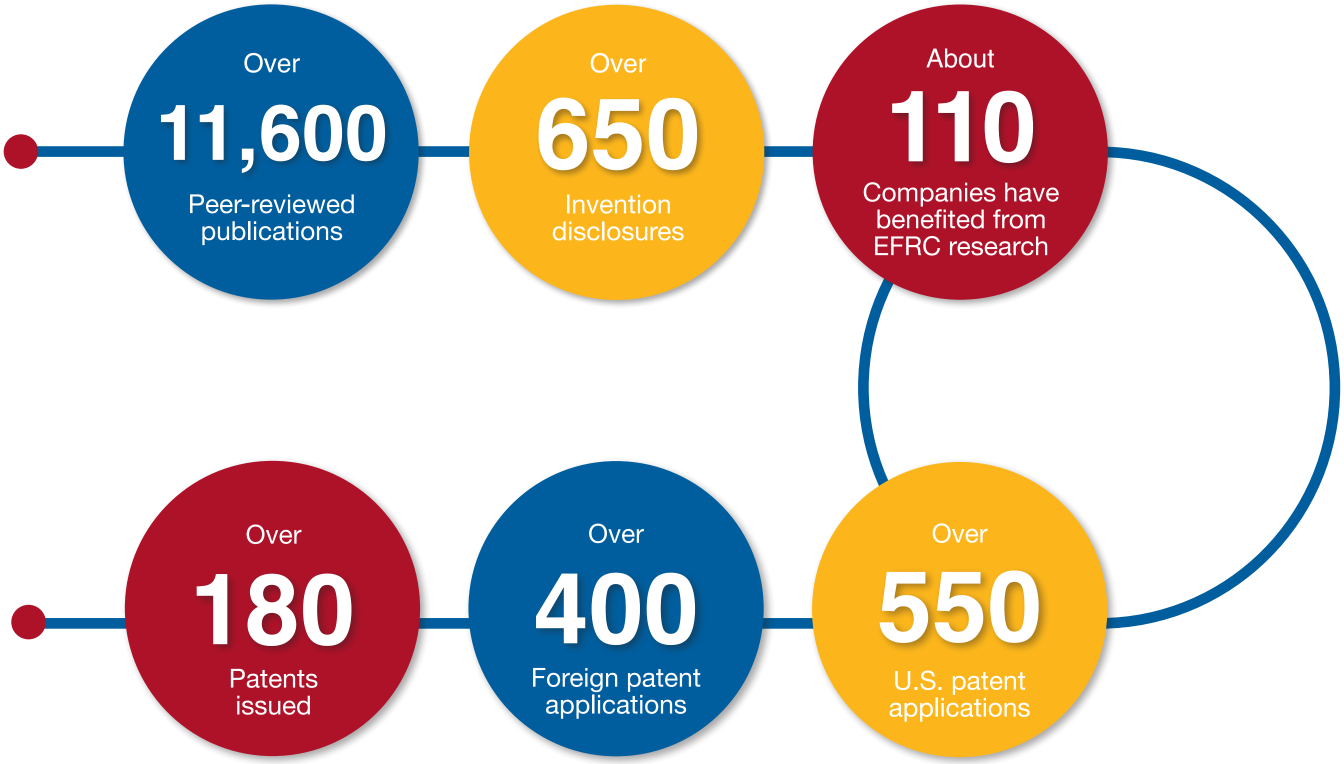


EFRC MEMBERS



EFRC IMPACT
BY THE NUMBERS

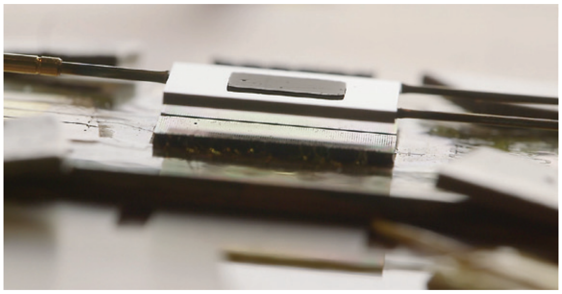
The EFRCs focus on grand challenge and use inspired science. Consequently, dissemination of scientific results through peer reviewed publications is the primary measure of success. However, the EFRCs also impact energy technology research and industry through licensing of patented inventions, transfer of scientific results to technology development projects, and collaborations with industry.



Cumulative numbers as of May 2019

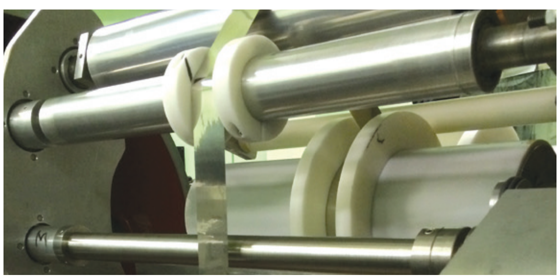
"EFRCs are my favorite way to do research. In the last decade, belonging to EFRCs has given me my most intriguing research questions, my most rewarding collaborations, and my most impactful research achievements. I have been challenged to develop new tools to expose how complex energy materials work, I have grown through leadership opportunities afforded me by the EFRCs, and I look forward to more in the future."

Professor Karena Chapman, Stony Brook University, has been involved in three EFRCs, contributing as a collaborator, senior investigator, and project leader. She is the Associate Director for A Next Generation Synthesis Center (GENESIS).



COMPANY SPIN-OFF

A thermophotovoltaic device converts thermal radiation from a heat source to electricity using a photovoltaic cell. Researchers at the Solid State Solar Thermal Energy Conversion Center created such a device based on one- and two-dimensional photonic crystals with improved power conversion efficiency compared to conventional power generation equipment. The device can be integrated into a novel energy storage architecture with lower cost than current lithium-ion battery technology. A new start-up company, Antora Energy, is working to commercialize this technology as a low-cost thermal battery for grid-scale energy storage.



INDUSTRY PARTNERSHIP

The Center for Emergent Superconductivity worked collaboratively with its industrial partner, American Superconductor, to develop the scientific basis for a rapid reel-to-reel ion irradiation process of high-temperature superconducting (HTS) wires to more than double their current-carrying capacity without altering their chemical makeup. Increasing the current-carrying capacity of HTS wires in the presence of high magnetic fields is critical for HTS-based rotating machine applications such as compact, lightweight wind turbines and motors, as well as various HTS magnet applications.

HIGHLY CITED PAPERS

- **A Revised Architecture of Primary Cell Walls Based on Biomechanical Changes Induced by Substrate-Specific Endoglucanases**
  Park, Y. B., and D. J. Cosgrove. 2012. *Plant Physiology* **158**, 1933–943. DOI: 10.1104/pp.111.192880.

- **Exciton Binding Energy and Nonhydrogenic Rydberg Series in Monolayer WS_2**
  Chernikov, A., et al. 2014. *Physical Review Letters* **113**, 076802. DOI: 10.1103/PhysRevLett.113.076802.

- **High-Rate Electrochemical Energy Storage Through Li^+ Intercalation Pseudocapacitance**
  Augustyn, V., et al. 2013. *Nature Materials* **12**, 518–22. DOI: 10.1038/NMAT3601.

- **Hydrocarbon Separations in a Metal-Organic Framework with Open Iron(II) Coordination Sites**
  Bloch, E. D., et al. 2012. *Science* **335**(6076), 1606–610. DOI: 10.1126/science.1217544.

- **Identifying Defect-Tolerant Semiconductors with High Minority-Carrier Lifetimes: Beyond Hybrid Lead Halide Perovskites**
  Brandt, R. E., et al. 2015. *MRS Communications* **5**(2), 265–75. DOI: 10.1557/mrc.2015.26.

- **Lead-Free Solid-State Organic-Inorganic Halide Perovskite Solar Cells**
  Hao, F., et al. 2014. *Nature Photonics* **8**, 489–94. DOI: 10.1038/NPHOTON.2014.82.

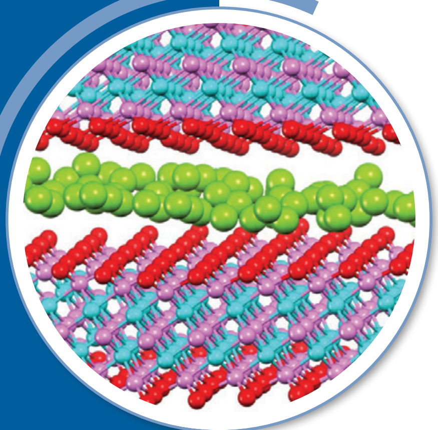
- **Microscopic Evidence for Liquid-Liquid Separation in Supersaturated $CaCO_3$ Solutions**
  Wallace, A. F., et al. 2013. *Science* **341**(6148), 885–89. DOI: 10.1126/science.1230915.

- **Next-Generation Lithium Metal Anode Engineering *via* Atomic Layer Deposition**
  Kozen, A. C., et al. 2015. *ACS Nano* **9**(6), 5884–892. DOI: 10.1021/acsnano.5b02166.

- **Sintering-Resistant Single-Site Nickel Catalyst Supported by Metal–Organic Framework**
  Li, Z., et al. 2016. *Journal of the American Chemical Society* **138**(6), 1977–982. DOI: 10.1021/jacs.5b12515.

- **Ultralow Thermal Conductivity and High Thermoelectric Figure of Merit in SnSe Crystals**
  Zhao, L.-D., et al. 2014. *Nature* **508**, 373–77. DOI: 10.1038/nature13184.

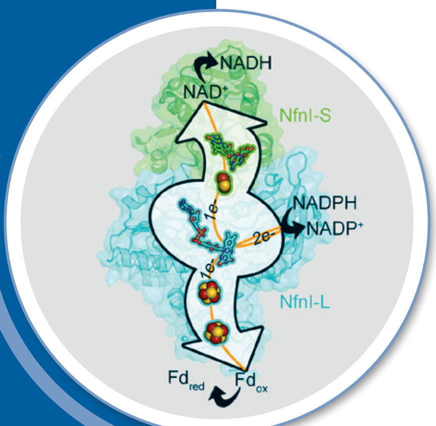
SCIENCE HIGHLIGHTS



A perfect match to improve energy storage capacity

Pairing electrolyte and electrode is essential for controlling the charge storage mechanism

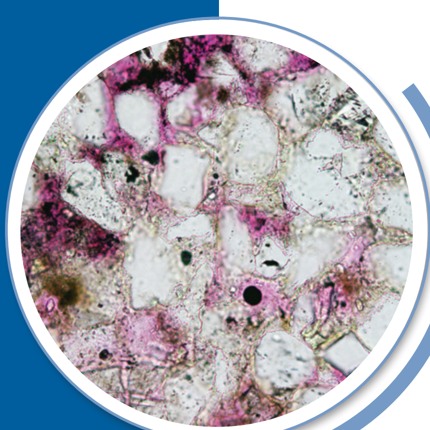
The slow charging speeds of batteries often limit their applications in electronics and vehicles. While supercapacitors allow for much faster charging, they currently lag behind batteries in their charge storage capacity. Researchers from the Fluid Interface Reactions, Structures and Transport Center increased the charge storage of a family of layered supercapacitor materials called MXenes by choosing the appropriate solvent for the electrolyte. The microscopic charging mechanisms were found to be highly dependent on the size and polarity of the solvent. These results highlight the need to optimize all components of the electrode-electrolyte system.



Flavins perform electron magic

Study explains how organisms extract energy from their environment

Electron bifurcation is a clever way to extract energy from metabolic processes where two intermediate-energy electrons are split to create one high- and one low-energy electron. Scientists at the Biological Electron Transfer and Catalysis Center studied bifurcation in the flavin cofactor, a compound related to the vitamin riboflavin. The study found a highly energetic, short-lived flavin intermediate created after the first electron is sent away. The flavin rapidly channels its energy to the remaining electron, bumping up its energy. The principles revealed provide a foundation for understanding how bifurcating enzymes merge unique cofactors with catalytic sites to accomplish biochemical reactions.



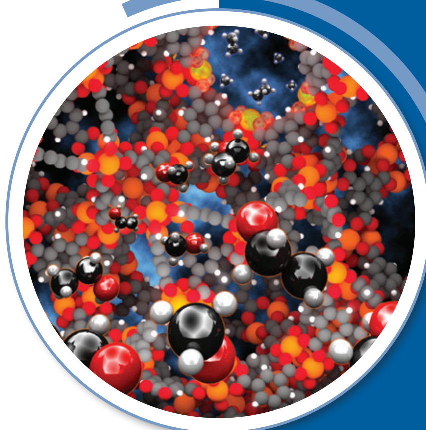
Fracture tests reveal clues to reservoir integrity

Carbon dioxide interacts with the local environment to impact long-term storage security

Researchers at the Center for Frontiers of Subsurface Energy Security investigated how the interactions among carbon dioxide (CO_2), water, and rock could affect the long-term storage of CO_2 underground. They analyzed the mineral components of rocks near naturally occurring CO_2 vents and found significant differences compared to nearby rocks that were exposed only to CO_2 in the air. Depending on the temperature, pressure, and mineral components of the rock, the CO_2 either creates cracks or forms a cement to seal the gas more securely within the rock. These results indicate that such long-term interactions may impact seal integrity over the design lifetime of a CO_2 reservoir.

Selective catalyst for transforming light alkanes

Computational study explains catalytic activity at low temperature



Propene is an important starting material for a wide variety of products, but it is usually made under harsh conditions that cause unavoidable side reactions. Scientists at the Inorganometallic Catalyst Design Center used a metal-organic framework (MOF) as a catalyst support to selectively produce propene from propane in the presence of oxygen. The cobalt catalyst was deposited in the MOF using two different approaches: solvothermal and atomic layer deposition. Both materials were catalytically active and selective for propene. Computational studies were used to propose a reaction mechanism that could lead to the design of improved catalysts.

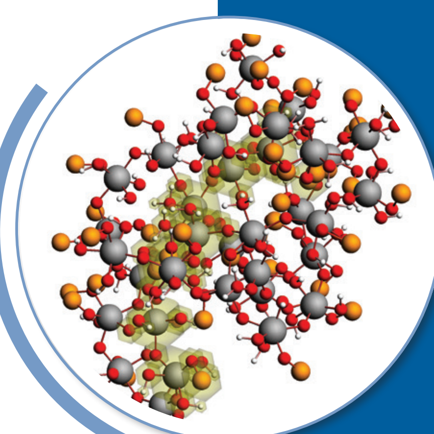
Turning wood scraps into tape

Raw non-food biomass is converted into a high-performance adhesive

Researchers at the Catalysis Center for Energy Innovation have developed a novel process that converts lignin—a substance that paper manufacturers typically burn or throw away—into high-performance pressure-sensitive adhesives (PSAs).These new polymeric PSAs exhibit high glass transition temperatures, robust thermal stabilities, excellent adhesion, and mechanical properties that may allow them to serve as renewable replacements for existing PSAs. Currently, PSAs are widely used as the backing that makes cellophane tape sticky. The properties of these new PSAs can be “tuned” (less sticky or more sticky) by modifying the catalyst.

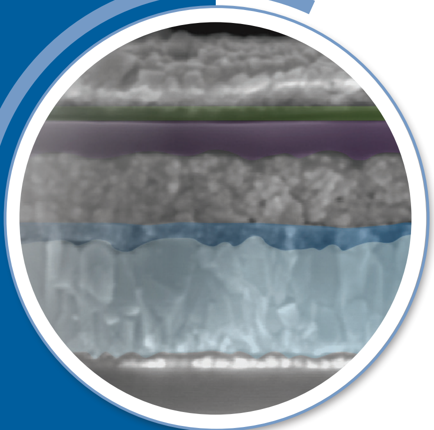
Understanding aluminum behavior in waste streams

Experimental and computational methods resolve similar aluminum species



Characterizing and controlling aluminum behavior in highly concentrated solutions are challenges in treating the nation’s high-level legacy radioactive waste streams. Recent research by the Interfacial Dynamics in Radioactive Environments and Materials EFRC used spectroscopy and computational methods to resolve three different aluminum species that form at high aluminum concentrations in alkaline conditions. Previous studies concluded that only a single species forms under similar conditions. The study also described the influence of ion pairing and solvent ordering. These results provide greater confidence in the design of aluminum separations processes for waste treatment.

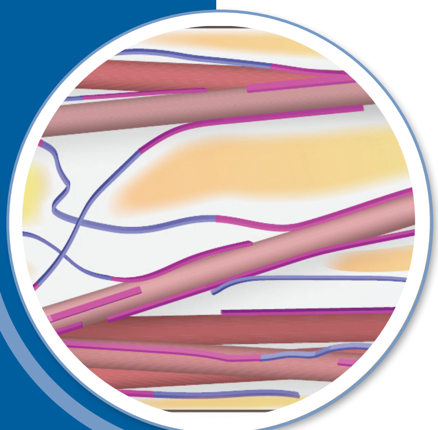
SCIENCE HIGHLIGHTS



Record-setting nanocrystals

New material could offer stable, low cost, and high-efficiency solar cells

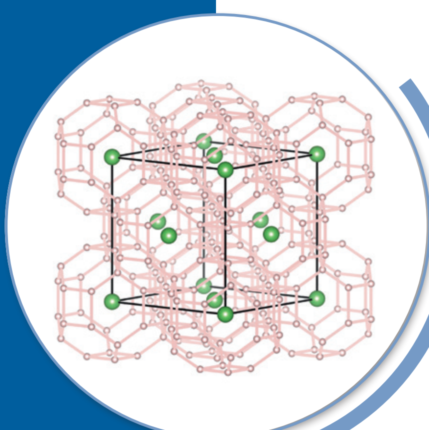
The physical and chemical properties of some materials change when confined to the volume of a nanoparticle. Researchers from the Center for Advanced Solar Photophysics discovered that the internal structure of all-inorganic perovskite ($CsPbI_3$) nanoparticles is different than bulk formulations of the same material. The nanoparticles have highly desirable light absorption properties and are more stable than larger crystals. A “glue” was developed to lock the nanocrystals together into conductive arrays. Photovoltaic cells made from the arrays had a power conversion efficiency of 13.4%, a world record for solar cells made from quantum dots.



Examining interactions in plant cell walls

Structure provides the basis for designing more digestible crops

Lignin is a complex biopolymer that strengthens and waterproofs plant secondary cell walls. Its removal is a key step in biomass conversion to biofuels. However, the physical nature of lignin’s interactions with wall polysaccharides, like xylan, is not well understood. Scientists at the Center for Lignocellulose Structure and Formation found that lignin self-aggregates to form highly hydrophobic and dynamically unique nanodomains. Studies of intact maize stems revealed that lignin interacts with the polar motifs of xylan. These findings advance our knowledge of the molecular-level organization of lignocellulosic biomass, providing the structural foundation for optimizing processing of biofuels.



First observation of near-room-temperature superconductivity

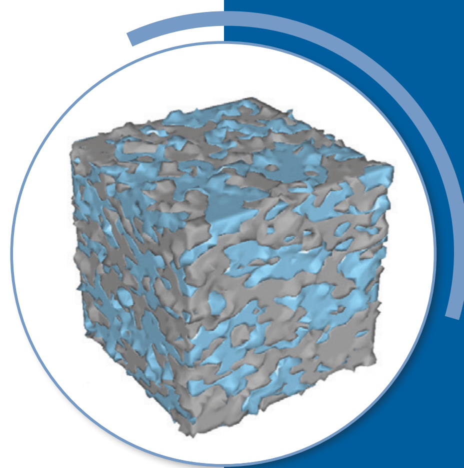
High-pressure hydrogen materials could lead to a new era of superconductivity

Room-temperature superconductivity has long been a coveted goal of physics. Researchers at the Energy Frontier Research in Extreme Environments Center synthesized several hydrogen-rich materials (lanthanum superhydrides) at high pressure that demonstrated superconductivity at record temperature. There was a sudden drop in electrical resistance at 7°C, the hallmark of a phase transition to superconductivity. Results could provide a road map for formulating other materials that behave similarly at ambient pressure, opening a pathway to practical superconductivity.

3D imaging of nanoporous water/solid interfaces

Center develops unique specimen preparation and handling protocol

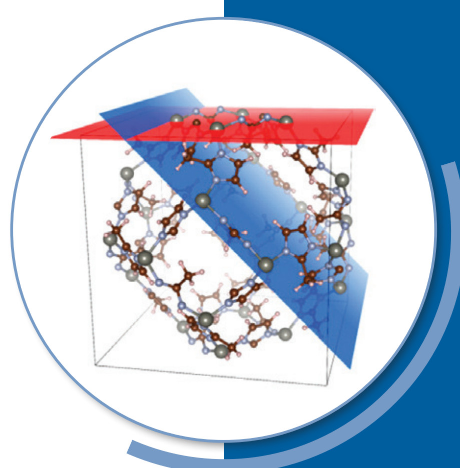
Liquid/solid interfaces are ubiquitous in nature, but many advanced analytical techniques are incompatible with mixed-phase systems. The Center for Performance and Design of Nuclear Waste Forms and Containers developed atom probe tomography methods to directly map and quantify the composition and morphology of water-filled porous structures formed during glass corrosion at the nanoscale by freezing the sample prior to analysis. The results will improve models of glass corrosion used to calculate the long-term durability of nuclear waste forms. More broadly, these methods can be used to study localized liquid/solid interfaces at surfaces or within nano-confined geometries.



Degradation behavior of crystalline microporous materials

Material stability is controlled by exposed surface facets

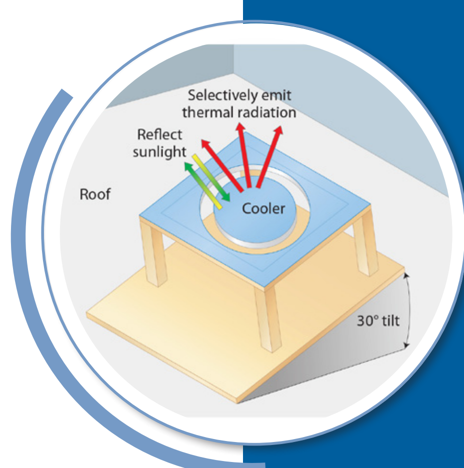
Zeolitic imidazolate frameworks (ZIFs) have been widely studied because of their thermal and chemical stability and potential use in gas adsorption, separation, and catalysis applications. However, most studies focus on the bulk structure, ignoring the potential effect of particle shape and the external surface. Scientists at the Center for Understanding and Control of Acid Gas-Induced Evolution of Materials for Energy examined the stability of two crystallographic facets of ZIF-8 after aqueous acid exposure. They identified which facet is more stable and studied their degradation behaviors. These insights provide guidelines for synthesizing stable ZIFs.



Electricity-free cooling

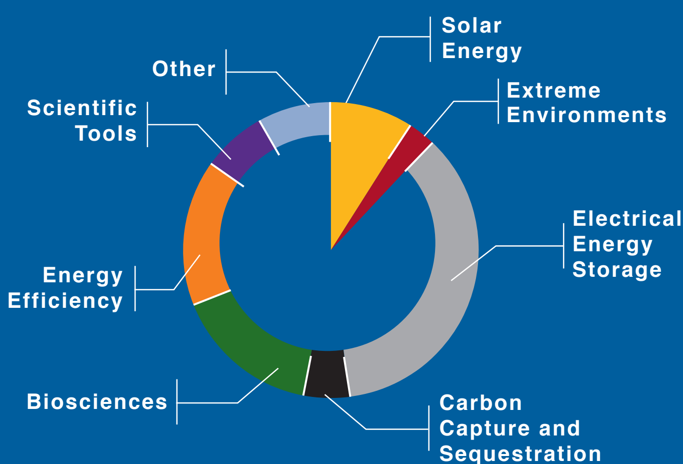
Daytime cooling is demonstrated using abundant materials in a simple device

On a hot, sunny day, surfaces such as asphalt can become blisteringly hot. Yet some materials stay cooler than the surrounding air even in direct sunlight. Scientists at the Light-Material Interactions in Energy Conversion Center demonstrated over 8°C cooling below the air's temperature using a simple device made from abundant, inexpensive materials. They developed a three-layer polymer-coated fused silica mirror that minimizes heating in direct sunlight. The device absorbs only a tiny fraction of sunlight and is highly reflective. These results open the door for passive cooling and reducing energy consumption.



SCIENCE COMMERCIALIZATION

The EFRCs provide an important bridge between basic research and energy technologies and complement other research activities funded by the U.S. Department of Energy. Some EFRC researchers are developing their basic research results into commercial products with funding from other federal and private sources. They are also forming new companies based on their EFRC research.



DISTRIBUTION OF COMPANIES THAT HAVE BENEFITTED FROM EFRC RESEARCH

EFRC interactions with companies span a wide range of energy research, as depicted in the chart above. Companies are involved with the EFRCs through licensing of EFRC intellectual property, establishing cooperative research and development agreements, using EFRC ideas in their business, providing follow-on funding, or maintaining substantial interactions involving personnel or sample exchange. The companies range in size as well: approximately 34% are start-ups, 20% are mid-size companies, and 46% are large companies.

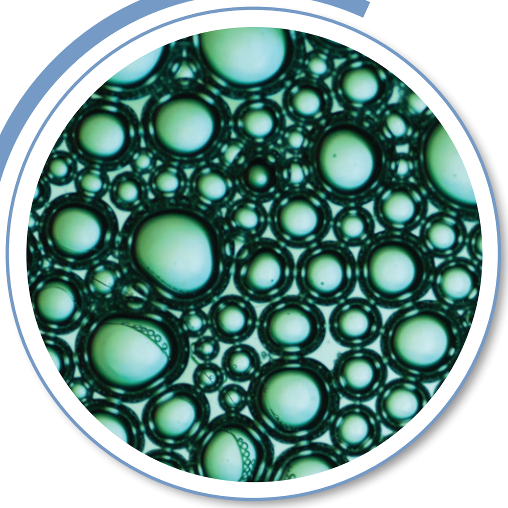
Quantum dot solar windows

BASIC SCIENCE

At the Center for Advanced Solar Photophysics (CASP), scientists developed the first large-area quantum dot luminescent solar concentrators free of toxic elements. By incorporating $CuInSe_xS_{2-x}$ quantum dots into a polymer matrix, they created freestanding slabs that introduce no distortion to perceived colors and are thus well suited for the realization of photovoltaic windows.

TECHNOLOGY TRANSFER

UbiQD, Inc., a start-up founded by an EFRC postdoctoral scholar, was formed to commercialize a novel, safe, low-cost, and reliable quantum dot technology. UbiQD foresees quantum dots soon becoming ubiquitous, and has maintained interactions with CASP, including joint publications, joint funding proposal submissions, and licensing of technologies. The company launched its first product, a luminescent greenhouse film for improving crop yield, secured more than $5 million in funding, and recently won a contract with NASA.



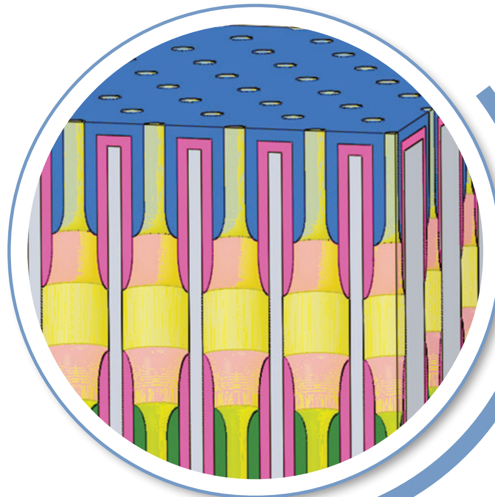
Surfactants from biomass

BASIC SCIENCE

Researchers at the Catalysis Center for Energy Innovation combined sugar-derived furans and seed oil-derived fatty acids to produce an entirely new class of surfactants for use in detergents. These surfactants have unprecedented stability in hard water, which is found in many U.S. homes. Hard water disrupts surfactant function and requires extensive use of undesirable and expensive additives. These new surfactants independently suppress the effects of hard water and are highly tunable for specific applications.

TECHNOLOGY TRANSFER

A start-up company, Sironix Renewables, was formed to commercialize this technology. To date, the company has earned over $2.5 million in seed capital to develop biorenewable surfactant technologies. Sironix Renewables has demonstrated proof of concept for use of its technology in detergents and cleaners. The company has also developed a scalable process design for rapid scale-up to production quantities.



Precision nanobatteries

BASIC SCIENCE

Research at the Nanostructures for Electrical Energy Storage (NEES) EFRC focuses on synthesis of precision electrochemical nanostructures, largely using thin film deposition methods that conform to challenging three-dimensional surface geometries like narrow tubes or pillars. Researchers constructed tiny batteries inside nanopores that stored energy efficiently at high power (fast charge and discharge) and survived extended cycling.

TECHNOLOGY TRANSFER

NEES has developed several versions of precision nanostructure arrays that combine high power and high energy. The versatility and control inherent in thin film fabrication of three-dimensional energy storage structures as demonstrated by NEES has led to significant industry interest, including collaborations and funding by several major companies to pursue applications in energy storage and beyond.

"The Center for Emergent Superconductivity's fundamental study of vortex pinning has been very beneficial to the development of AMSC's 2G wire (see Industry Partnership, p. 5). Their development of predictive models and testing in real conductors has guided the direction of AMSC's research and development efforts and has enabled the demonstration of a low cost, reel to reel process for significantly enhancing the critical current of AMSC's standard 2G HTS wire. The basic science studies carried out by the Center for Emergent Superconductivity's research team have provided essential insight into critical material issues that AMSC is unable to address on its own."

Dr. Martin Rupich, Senior Technical Manager of R&D, American Superconductor

amsc®

EFRC COMMUNICATIONS

EFRC MEETINGS

EFRC Principal Investigators (PI) meetings are held biennially in Washington, D.C., to strengthen connections within the EFRC community. Starting in 2011, between 500 and 1,000 of America's top energy researchers and policymakers have attended each meeting (see Meetings at www.energyfrontier.us). These events included plenary talks, scientific oral and poster presentations from all the EFRCs, and a student and postdoc competition. The meetings have also included diversity events, panel discussions, science communication contests, and networking events.

FRONTIERS IN ENERGY RESEARCH NEWSLETTER

The EFRCs have established effective collaborations and communication strategies, particularly through the EFRC Community Website (www.energyfrontier.us). EFRC early career scientists started the Frontiers in Energy Research newsletter, which contains quarterly research highlights selected and written by early career scientists invested in the public communication of science.

EARLY CAREER NETWORK

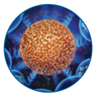
The Basic Energy Sciences Early Career Network (BES ECN) is a group of graduate students, postdoctoral researchers, and early career scientists from current EFRCs, Energy Innovation Hubs, Computational Materials Sciences awards, and Computational Chemical Sciences awards. The goal is to share best practices between centers, provide workforce development opportunities, and create a network of early career scientists with a passion for energy science. The BES ECN plans webinars, hosts meet-ups at national meetings, and organizes early career events at Principal Investigators meetings.

"The EFRC culture of networking gave me unique opportunities to develop leadership and communication skills and connect and work with members at other EFRCs. I was fortunate to join the EFRC Newsletter Editorial Board, and our *Sound ∩ Science* podcast won an award for Best Team Effort. My participation in the Energy Dissipation to Defect Evolution (EDDE) center and the larger EFRC community allowed me to grow both personally and professionally in a vibrant environment of diverse, talented researchers dedicated to advancing energy technologies."

Dr. Eva Zarkadoula, R&D Associate, Oak Ridge National Laboratory

IMAGE CREDITS

FRONT COVER



Fundamental catalytic studies can be linked to real catalyst performance by using controlled pulses of reactants over a wide pressure range. Integrated Mesoscale Architectures For Sustainable Catalysis. Courtesy Jeff Miller.

PAGE 1

All-hands meeting for the Center for Synthetic Control Across Length-Scales for Advancing Rechargeables (SCALAR). Courtesy SCALAR.

PAGE 4

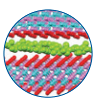
Karena Chapman. A Next Generation Synthesis Center. Courtesy Karena Chapman.

PAGE 5

Thermophotovoltaic device converts thermal radiation to electricity. Solid State Solar Thermal Energy Conversion Center. Courtesy John Freidah, Massachusetts Institute of Technology.

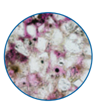
Reel-to-reel set-up for ion irradiation of high-temperature superconducting wires. Center for Emergent Superconductivity. Courtesy American Superconductor Corporation.

PAGE 6



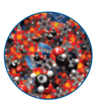
A perfect match to improve energy storage capacity. Fluid Interface Reactions, Structures and Transport Center. Courtesy Sheng Dai. More information: Wang, X., et al. 2019. "Influences from Solvents on Charge Storage in Titanium Carbide MXenes." *Nature Energy* **4**, 241-48. DOI: 10.1038/s41560-019-0339-9.

Flavins perform electron magic. Biological Electron Transfer and Catalysis Center. Reprinted by permission from Macmillan Publishers Ltd: Nature Chemical Biology. Lubner, C. E., et al. 2017. "Mechanistic Insights into Energy Conservation by Flavin-Based Electron Bifurcation." *Nature Chemical Biology* **13**(6), 655–59. DOI: 10.1038/nchembio.2348. © 2017.



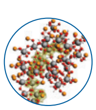
Fracture tests reveal clues to reservoir integrity. Center for Frontiers of Subsurface Energy Security. Reprinted by permission from Major, J. R., et al. 2018. "Effect of CO_2-Brine-Rock Interaction on Fracture Mechanical Properties of CO_2 Reservoirs and Seals." *Earth and Planetary Science Letters* **499**, 34-47. DOI: 10.1016/j.epsl.2018.07.013. © 2018 Elsevier.

PAGE 7



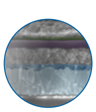
Selective catalyst for transforming light alkanes. Catalyst Design Center. Reprinted by permission from Vitillo, J. G., et al. 2019. "Quantum Chemical Characterization of Structural Single Fe(II) Sites in MIL-Type Metal-Organic Frameworks for the Oxidation of Methane to Methanol and Ethane to Ethanol." *ACS Catalysis* **9**(4), 2870-79. DOI: 10.1021/acscatal.8b04813. © 2019 American Chemical Society.

Turning wood scraps into tape. Courtesy Catalysis Center for Energy Innovation. More information: Wang, S., et al. 2018. "From Tree to Tape: Direct Synthesis of Pressure Sensitive Adhesives from Depolymerized Raw Lignocellulosic Biomass." *ACS Central Science* **4**(6), 701-08. DOI: 10.1021/acscentsci.8b00140.

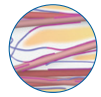


Understanding aluminum behavior in waste streams. Interfacial Dynamics in Radioactive Environments and Materials. Courtesy Jianzhi Hu. More information: Hu, J. Z., et al. 2017. "Transitions in Al Coordination During Gibbsite Crystallization Using High-Field ^{27}Al and ^{23}Na MAS NMR Spectroscopy." *Journal of Physical Chemistry C* **121**(49), 27555-65. DOI: 10.1021/acs.jpcc.7b10424.

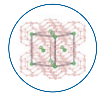
PAGE 8



Record-setting nanocrystals. Center for Advanced Solar Photophysics. Used with permission under a Creative Commons license (CC-BY-NC 4.0) from Sanehira, E. M., et al. 2017. "Enhanced Mobility $CsPbI_3$ Quantum Dot Arrays for Record-Efficiency, High-Voltage Photovoltaic Cells." *Science Advances* **3**(10), eaao4204. DOI: 10.1126/sciadv.aao4204.

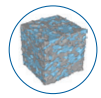


Examining interactions in plant cell walls. Center for Lignocellulose Structure and Formation. Used with permission under a Creative Commons license (CC-BY-NC 4.0) from Kang, X., et al. 2019. "Lignin-Polysaccharide Interactions in Plant Secondary Cell Walls Revealed by Solid-State NMR." *Nature Communications* **10**, 347. DOI: 10.1038/s41467-018-08252-0.

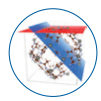


First observation of near-room-temperature superconductivity. Energy Frontier Research in Extreme Environments Center. Courtesy Hanyu Liu. From Geballe, Z. M., et al. 2017. "Synthesis and Stability of Lanthanum Superhydrides." *Angewandte Chemie* **57**(3), 688–92. DOI: 10.1002/anie.201709970. © 2018 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.

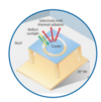
PAGE 9



3D imaging of nanoporous water/solid interfaces. Center for Performance and Design of Nuclear Waste Forms and Containers. Courtesy D. E. Perea and D. K. Schreiber, Pacific Northwest National Laboratory. More information: Schreiber, D. K., et al. 2018. "A Method for Site-Specific and Cryogenic Specimen Fabrication of Liquid/Solid Interfaces for Atom Probe Tomography." *Ultramicroscopy* **194**, 89-99. DOI: 10.1016/j.ultramic.2018.07.010.



Degradation behavior of crystalline microporous materials. Center for Understanding and Control of Acid Gas-Induced Evolution of Materials for Energy. Reprinted by permission from Pang, S. H., et al. 2016. "Facet-Specific Stability of ZIF-8 in the Presence of Acid Gases Dissolved in Aqueous Solutions." *Chemistry of Materials* **28**, 6960–67. DOI: 10.1021/acs.chemmater.6b02643.

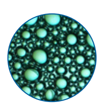


Electricity-free cooling. Light-Material Interactions in Energy Conversion Center. More information: Kou, J. L., et al. 2017. "Daytime Radiative Cooling Using Near-Black Infrared Emitters." *ACS Photonics* **4**(3), 626-30. DOI: 10.1021/acsphotonics.6b00991.

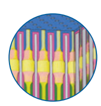
PAGE 10

Quantum dot solar windows. Center for Advanced Solar Photophysics. Courtesy UbiQD, Inc. More information: Meinardi, F., et al. 2015. "Highly Efficient Large-Area Colourless Luminescent Solar Concentrators Using Heavy-Metal-Free Colloidal Quantum Dots." *Nature Nanotechnology* **10**, 878-85. DOI: 10.1038/nnano.2015.178.

PAGE 11



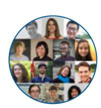
Surfactant from biomass. Catalysis Center for Energy Innovation. Courtesy Paul Dauenhauer, Sironix Renewables. More information: Park, D. S., et al. 2016. "Tunable Oleo-Furan Surfactants by Acylation of Renewable Furans." *ACS Central Science* **2**(11), 820-24. DOI: 10.1021/acscentsci.6b00208.



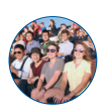
Precision nanobatteries. Nanostructures for Electrical Energy Storage. Liu, C., et al. 2014. "An All-in-One Nanopore Battery Array," *Nature Nanotechnology* **9**, 1031–39. DOI:10.1038/nnano.2014.247.

PAGE 12

EFRC meetings. Courtesy Natalia Melcer.

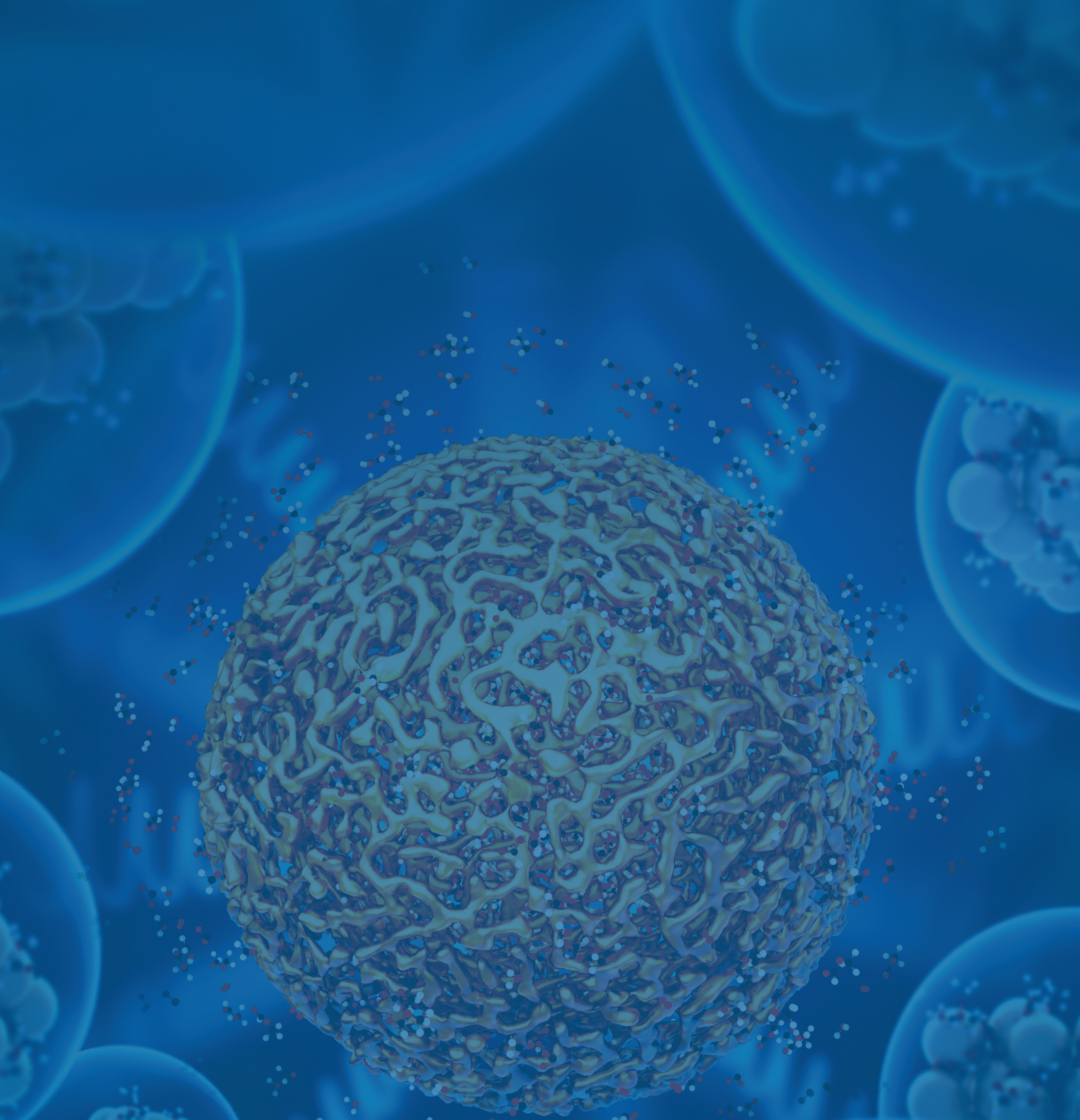


Frontiers in Energy Research Newsletter. Members of the newsletter editorial board. Courtesy Natalia Melcer.



Early Career Network. Early career network outing to a baseball game during the EFRC Principal Investigators meeting. Courtesy Michael Guerette.

Eva Zarkadoula. Energy Dissipation to Defect Evolution. Courtesy Eva Zarkadoula.



DISCLAIMER: This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufac turer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government.

Contact
Basic Energy Sciences
U.S. Department of Energy
SC-22/Germantown Building
1000 Independence Ave., SW
Washington, D.C. 20585
sc.bes@science.doe.gov
Phone: 301.903.3081
Fax: 301.903.6594
science.osti.gov/bes/efrc