AMERICAN CERAMIC SOCIETY
bulletin
emerging ceramics & glass technology
JANUARY/FEBRUARY 2022

Toward a renewable energy future—flow batteries and solid oxide fuel cells

DOE's Advanced Manufacturing Office | Federal FY22 budget proposals | Meet ACerS president

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feature articles

Correction to the Dec. 2021 *ACerS Bulletin*

In the print edition of the December 2021 *Bulletin*, II-VI Aerospace & Defense's website was listed incorrectly in the advertiser's index on page 59. The website should be www.iiviad.com. The website is listed correctly in the digital version.

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As seen on *Ceramic Tech Today*...

Credit: National Renewable Energy Lab, Flickr (CC BY-NC-ND 2.0)

Video: Floating solar projects around the world

While Japan and China lead the market for floating solar parks, more countries are investing in this technology. This CTT highlights several recent floating solar projects around the world, as well as a few floating wind projects.

Read more at www.ceramics.org/floating-solar

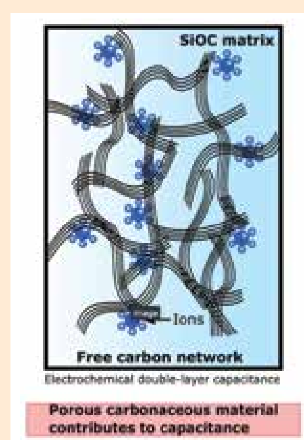
Also see our ACerS journals...

The Energy Materials and Systems Division is organizing a special issue of *Journal of the American Ceramic Society* entitled "Energy Materials for Sustainable Development." If your research surrounds fundamental science for advanced energy materials, the guest editors look forward to reviewing your next manuscript. Submit your manuscript to https://mc.manuscriptcentral.com/jacers and note the special issue in the cover letter and in step 6 of the questions.

Polymer derived SiOC and SiCN ceramics for electrochemical energy storage: A perspective
By S. B. Mujib and G. Singh
International Journal of Ceramic Engineering & Science

Additive manufacturing of novel 3D ceramic electrodes for high-power-density batteries
By A. S. Almansour, A. J. Gorven, and M. Singh
International Journal of Applied Ceramic Technology

Heterostructure interface effect on the ORR/OER kinetics of Ag–$PrBa_{0.5}Sr_{0.5}Co_2O_{5+\delta}$ for high-efficiency Li–O_2 battery
By L. Zou, Z. Lu, Z. Wang, B. Chi, and J. Pu
Journal of the American Ceramic Society



Journal of the American Ceramic Society | International Journal of Applied Ceramic Technology | International Journal of Applied Glass Science | International Journal of Ceramic Engineering & Science

Read more at www.ceramics.org/journals

American Ceramic Society Bulletin covers news and activities of the Society and its members, includes items of interest to the ceramics community, and provides the most current information concerning all aspects of ceramic technology, including R&D, manufacturing, engineering, and marketing. The American Ceramic Society is not responsible for the accuracy of information in the editorial, articles, and advertising sections of this publication. Readers should independently evaluate the accuracy of any statement in the editorial, articles, and advertising sections of this publication. *American Ceramic Society Bulletin* (ISSN No. 0002-7812). ©2022. Printed in the United States of America. *ACerS Bulletin* is published monthly, except for February, July, and November, as a "dual-media" magazine in print and electronic formats (www.ceramics.org). Editorial and Subscription Offices: 550 Polaris Parkway, Suite 510, Westerville, OH 43082-7045. Subscription included with The American Ceramic Society membership. Nonmember print subscription rates, including online access: United States and Canada, 1 year $135; international, 1 year $150.* Rates include shipping charges. International Remail Service is standard outside of the United States and Canada. *International nonmembers also may elect to receive an electronic-only, email delivery subscription for $100. Single issues, January–October/November: member $6 per issue; nonmember $15 per issue. December issue (*ceramicSOURCE*): member $20, nonmember $40. Postage/handling for single issues: United States and Canada, $3 per item; United States and Canada Expedited (UPS 2nd day air), $8 per item; International Standard, $6 per item.

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ACSBA7, Vol. 101, No. 1, pp 1– 48. All feature articles are covered in Current Contents.

Recent Chinese and Russian hypersonic test launches underscore importance of expanding US materials science R&D

By David A. Gottfried

While there is some plausible deniability one could maintain regarding China's intentions following the August 2021 launch of a purported reusable hypersonic space vehicle as a "cheap way for humans to use space peacefully," the intentions from Russia's recent submarine-based test firing of a hypersonic cruise missile are far clearer: pierce U.S. defenses. How advanced Russia's systems are remains to be seen, with U.S. officials doubting the readiness or functionality of these Russian weapons. The reported "surprise" that U.S. intel agencies expressed following the Chinese launch may or may not be accurate, but it is nonetheless concerning. The message is also clear that our adversaries' investments in hypersonic systems as the next generation of advanced weaponry puts U.S. national security at significant risk.

Hypersonic weapon systems—i.e., boosted glide vehicles, scramjet cruise missiles, or maneuverable quasi-ballistic missiles—pose a significant air defense challenge. Hypersonic cruise missiles, specifically, operate at lower altitudes with maneuverability, making them harder to detect and kill than legacy ballistic and cruise missiles. However, these hypersonic systems are not invulnerable.

A major thrust in developing U.S. hypersonic defensive (and offensive) capabilities lies in the development of advanced materials that are designed to operate under the harsh conditions that hypersonic systems are subjected to. One such area includes advanced or technical ceramic materials. Ceramics possess unique properties that enable devices to better manage the mechanical stresses, heat, friction, and other forces that alternative classes of materials would be poorly suited for.

The importance of ceramics to multiple industrial sectors is often hard to explain: Most Americans think of ceramics as nothing more than teapots and toilets. However, technical ceramics and glass are what makes our mobile phones, computers, fiber optic/broadband communications, and thousands of other technologies possible. They're also one of our best bets for countering hypersonic threats from China, Russia, North Korea, Iran, or any of our other adversaries.

Whether recent developments by the Russians and Chinese represent an existential threat to domestic security, it would be most prudent to act as if they were. We know these systems and materials are well on their way. We also know that the U.S. has similarly been making investments in these materials classes for many years. However, not only must funding for materials research for hypersonic applications continue, but they must also be significantly expanded upon. Furthermore, U.S.-based academic institutions can leverage their faculties unique expertise of ceramic materials to lead the way in countering these threats.

Alfred University has studied advanced ceramic materials for over 120 years and is well positioned to help address these needs. Then-New York State governor Theodore Roosevelt officially authorized the New York State College of Ceramics in 1900. The College, managed by Alfred University, has been at the cutting edge of materials research ever since, from technology focused on glass strengthening to new materials for energy storage, to developing high-temperature characterization techniques to improve material performance and eliminate failures.

Later as President of the United States, Roosevelt used the West African proverb, "Speak softly and carry a big stick; you will go far," as helping to define his approach to foreign policy. A major tenet of Roosevelt's big stick diplomacy focused on "the exercise of intelligent forethought and of decisive action sufficiently far in advance of any likely crisis." It also relied on significant military might.

The United States has known for some time that hypersonic systems were under development elsewhere and has similarly made investments in our own countermeasures and offensive systems. Due in large part to the current COVID-19 pandemic, we are experiencing the negative impacts of foreign investments in areas such as semiconductor manufacturing, specifically how supply chain reliance on China is negatively impacting the nation's economic security. These latest moves by China and Russia clearly illustrate that the U.S. must move decisively in the development of next-generation ceramic materials such that our foreign adversaries are not the ones dictating the terms of U.S. foreign policy positions, putting our domestic security in peril, and leading us toward crisis.

David A. Gottfried is deputy director of the Center for Advanced Ceramic Technologies at Alfred University's New York State College of Ceramics. He can be reached at gottfried@alfred.edu.

The American Ceramic Society publishes Letters to the Editor to give individuals a forum to express their opinions. These opinions do not reflect positions or policies of the Society.

international year of glass

Each month, we will be highlighting articles from different areas of glass science in the online blog *Ceramic Tech Today.*

The American Ceramic Society journals celebrate the International Year of Glass

By John C. Mauro

Glass is such an integral and ubiquitous part of our lives—in our homes, our vehicles, our computers, our phones—that life would be unrecognizable without this most lustrous and versatile of materials. Our world is connected by glass optical fibers through which we communicate at the speed of light, by glass touchscreens that form the interface between humanity and the internet, by glass windows through which we view the outside world, and by glass vials that can store critical life-saving vaccines and medicine.

In recognition of the vital importance of glass in the development of contemporary civilization and the many future opportunities of glass to address critical global challenges, the United Nations General Assembly declared 2022 to be the International Year of Glass (IYoG). The goals of the IYoG are to celebrate the essential role of glass in our society, in the past and in the future, and to promote glass education around the world.

The idea for the IYoG was conceived in 2016 by L. David Pye, past president of The American Ceramic Society and founding editor-in-chief of the *International Journal of Applied Glass Science.* Joining forces with leaders from the International Commission on Glass (ICG), Pye led a successful multiyear campaign to translate his vision into reality.

ACerS has several activities planned to celebrate the IYoG, including a special issue of the *International Journal of Applied Glass Science* and a National Day of Glass, taking place on April 5–7 in Washington, D.C., as well as special programming at the Annual Meeting of the Glass & Optical Materials Division (GOMD) on May 22–26, 2022, in Baltimore, Md.

As part of the IYoG celebrations, ACerS is presenting the series "Glass: Then and Now," which highlights ACerS journal articles that have played historically critical roles in advancing glass science and technology, as well as recently published articles that are setting future directions for the field. With more than a century in print, *Journal of the American Ceramic Society* has published many of the most important and influential articles in the history of glass science. Today, *Journal of the American Ceramic Society* and *International Journal of Applied Glass Science* continue to set the standard of excellence for publications in glass science and engineering.

The articles in the "Glass: Then and Now" series were compiled by Jincheng Du and John Mauro (editors, *Journal of the American Ceramic Society*), Mario Affatigato (editor-in-chief, *International Journal of Applied Glass Science*), and Bill Fahrenholtz (editor-in-chief, *Journal of the American Ceramic Society*).

Each month, we will be highlighting articles from different areas of glass science in the online blog *Ceramic Tech Today.*

January: Optical fibers and photonics
February: Glass toughness and mechanical properties
March: Chemically strengthened glass
April: Bioactive glasses
May: Glass durability and reactions with water
June: Glass for nuclear waste disposal
July: Viscosity and fictive temperature
August: Glass relaxation
September: Molecular dynamics simulations
October: Glass topology and artificial intelligence
November: Glass-ceramics
December: Glass under pressure

In each of these areas, we will feature groundbreaking articles from the past that have transformed our thinking about glass, as well as recently published articles that are defining the current state-of-the-art understanding of glass and the paving the way for the future. With this "Glass: Then and Now" series, we celebrate the long heritage of pioneering articles published in ACerS journals, which continues today, stronger than ever.

The complete list of articles can be found at https://ceramics.org/gtan or by visiting the Topical Collections webpage on ACerS Publication Central at https://bit.ly/ACerSTopicalCollections. The articles in each topic will be made free-to-read in the month they are highlighted.

About the author

John C. Mauro is professor and associate head in the Department of Materials Science and Engineering at The Pennsylvania State University. Contact Mauro at jcm426@psu.edu. ■

news & trends

Federal budget 2022—Focus on special spending bills slows appropriations negotiations

By Lisa McDonald

October 1 marked the official start of the United States fiscal year 2022 (FY22). Congress did not complete action on appropriations before the end of FY21 on September 30. To avoid a shutdown, Congress passed and President Joe Biden signed two continuing resolutions to fund the government through December 3 and February 18, respectively.

Since Democrats took control of both the House and Senate by very slim margins in the 2021 election, a major focus for Congress has been the development of two special spending bills that are meant to fulfill many of Biden's promises during the 2020 campaign. The $1.2 trillion bipartisan Infrastructure Investment and Jobs Act, which Biden signed into law on November 15, focuses on investments in transportation and other infrastructure, such as roads, railways, bridges, and broadband internet.

The second bill, called Build Back Better, focuses on social and climate spending, and it faces more opposition to passage. Biden originally proposed $3.5 trillion for the bill but has since scaled it back to $1.75 trillion. The House passed the bill on November 19, and it is now in the Senate for negotiations.

With the attention these two special spending bills have received, negotiations on the FY22 appropriations bills are running behind schedule. However, at this point, both the House and Senate have released all their proposals, so reconciliation between the two houses of Congress can begin.

The Senate and House bills both seek significant boosts across science programs, including double-digit percentage increases for the National Science Foundation, National Institutes of Health, and National Institute of Standards and Technology, among other agencies. But there are points of disagreement that need to be resolved. Senate appropriators seek to increase funding for early-stage defense R&D, whereas the House and White House propose cuts. Conversely, Senate appropriators are proposing considerably smaller increases for the Advanced Research Projects Agency–Energy and U.S. Geological Survey than the increases proposed by the House.

A few highlights from the proposals:

Department of Defense

The Department of Defense's research, development, test, and evaluation (RDT&E) budget would increase by 2% or 7%, respectively, in fiscal year 2022 based on proposals from the House and Senate. However, appropriators split ways in their proposals for funding the Department of Defense's Science and Technology portfolio under RDT&E, with the House proposing a 5% cut to the current $16.9 billion topline and the Senate a 5% increase. The Senate proposes a particularly large boost for the Defense Advanced Research Projects Agency, seeking a 12% increase to just under $4 billion, while the House proposes flat funding for the agency.

National Science Foundation

House and Senate appropriators propose raising the current $8.5 billion annual budget of the National Science Foundation by about $1 billion in fiscal year 2022, which is short of the $1.7 billion increase the White House requested.

Both bills support the proposal to create a new, technology-focused NSF directorate, which has received widespread bipartisan support. The Senate report directs NSF to allocate up to $865 million for the directorate in its first year, matching the agency's proposed level, while the House report does not specify an amount. Congress is still debating legislation to formally authorize the directorate and define its role in statute.

Department of Energy

The White House requested to increase DOE's budget from $39.6 billion to $46.2 billion. Both the House and Senate proposals are in line with the request, with recommended increases to the total budget being $45.1 billion and $45.3 billion, respectively.

Office of Science: House and Senate appropriators propose raising the DOE Office of Science budget 4% and 7%, respectively, to $7.3 billion and $7.5 billion. The topline differences between the proposals are most pronounced for the Nuclear Physics and Fusion Energy Sciences programs. The House proposes to increase funding for Fusion Energy Sciences by 4% to $698 million, while the Senate proposes a 2% cut to $660 million for the program, reflecting a proposed reduction in the U.S. contribution to construction of the international ITER facility. In contrast, the Energy Act of 2020 recommends that Congress fund the program at nearly $1 billion in fiscal year 2022 to accommodate increased contributions to ITER as well as a pivot toward laying groundwork for a U.S.-based fusion power industry.

Applied energy R&D: For fiscal year 2022, the White House asked Congress to significantly expand the applied research, development, and demonstration programs' annual budgets. The responding proposals from House and Senate appropriators mostly do not meet the requested amounts, though they still provide major increases across most programs. Both proposals deny the administration's request to move forward with design work on a new, multibillion-dollar nuclear energy R&D facility called the Versatile Test Reactor. They also reject the administration's request to create an Advanced Research Projects Agency for climate-related R&D, citing the absence of the legislative authorization needed to set up a new agency.

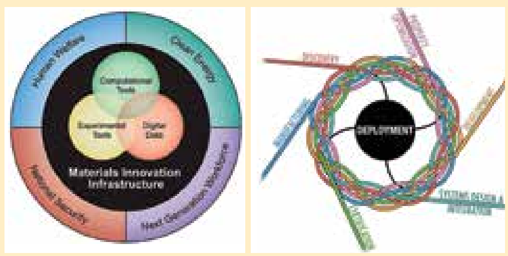
National Nuclear Security Administration

Following five years of rapid growth, the NNSA budget would level off near $20 billion under the House's and Senate's spending proposals for fiscal year 2022. However, among NNSA R&D programs, the House and Senate

Materials Genome Initiative updates strategic plan

By Eileen De Guire

In 2011, President Barack Obama introduced the Materials Genome Initiative—an ambitious vision to accelerate new materials discovery and increase global competitiveness of U.S. businesses.



Credit: National Science and Technology Council Subcommittee

Figure 1. The United States National Science and Technology Council Subcommittee on the Materials Genome Initiative has issued a new strategic plan (right). The new plan builds on the advances made since the MGI was established in 2011 (left).

The goal of the MGI was to reduce the time for materials development-to-deployment by 50%, or about 10 years—and for less cost. The MGI was motivated by the urgent need for new materials solutions for national challenges in clean energy, national security, and human welfare.

The authors of the 2011 MGI whitepaper understood that success would require building an infrastructure of computational tools, experimental tools, collaborative networks, and digital data. A four-part strategic plan drove the first decade of the MGI:

1. Equip the next-generation materials workforce;
2. Enable a paradigm shift in materials development;
3. Integrate experiments, computation, and theory; and
4. Facilitate access to materials data.

In November 2021, the NSTC subcommittee marked the 10th anniversary of the MGI by issuing a new, comprehensive five-year strategic plan for the MGI. The new strategic plan builds on the momentum sparked by the original MGI and sharpens the focus of the MGI's potential to drive materials innovation, especially with respect to deploying new materials into service. A side-by-side "then and now" comparison of the MGI shows how the new strategy expands on advances made in the last decade and anticipates a shift to manufacturing (Figure 1).

The document's stated goal is to provide "a vision to align the MGI community across the continuum from research and development through deployment, and identifies goals for the next five years with objectives and actions to be taken by the community to advance the MGI."

This new strategic plan comprises three goals:

1. Unify the materials innovation infrastructure;
2. Harness the power of materials data; and
3. Educate, train, and connect the materials R&D workforce.

Learn more about the MGI and its history at https://www.mgi.gov/about. ■

Table 1. FY22 budget proposals ($ in millions)

	DOD S&T total	NSF	DOE Office of Science	NIST	NASA	NIH
FY21 appropriation	16,873	8,487	7,026	1,035	7,301	42,934
White House	14,685 (-13%)	10,169 (20%)	7,440 (6%)	1,496 (45%)	7,931 (9%)	51,953 (21%)
House	16,009 (-5%)	9,634 (14%)	7,320 (4%)	1,369 (32%)	7,970 (9%)	49,434 (15%)
Senate	17,672 (5%)	9,487 (12%)	7,490 (7%)	1,394 (35%)	7,901 (8%)	47,923 (12%)

proposals do significantly exceed the administration's request in areas such as stockpile assessment science and inertial confinement fusion.

National Institute of Standards and Technology

House and Senate appropriators propose increasing the $1 billion annual budget of the National Institute of Standards and Technology by more than 30%. The increases are among the highest in percentage terms proposed across science agencies this budget cycle, though they fall short of the 45% increase requested by the White House.

This budget cycle is the first since 2011 that appropriators permitted earmarks for particular projects. The Senate report earmarks $38 million to fund 20 projects at universities across the U.S. The House Appropriations Committee also permitted earmarks but made none for NIST.

Outside the regular appropriations process, NIST may benefit from special spending legislation currently under development. There is a bipartisan push to spend $52 billion on domestic semiconductor manufacturing and R&D over five years to implement initiatives recently authorized through the CHIPS for America Act. Of this total, the Senate-passed U.S. Innovation and Competition Act (USICA) would allocate $3 billion directly to NIST for semiconductor R&D in fiscal year 2022 alone, with further funding in future years. The House has not yet indicated if it will follow suit in providing this funding.

National Aeronautics and Space Administration

House and Senate proposals for NASA's fiscal year 2022 science budget are in near agreement with the administration's proposal to increase the budget from $7.30 billion to $7.93 billion, with the House providing about $40 million more than that and the Senate $30 million less.

The Planetary Science and Earth Science Divisions are in line for particularly significant increases under both proposals. However, there remains some doubt over the fate of the SOFIA airborne telescope because House appropriators rejected the administration's proposal to terminate it; Senate appropriators have not ruled it out.

National Institutes of Health

Senate appropriators proposes a $5 billion increase to $49.4 billion for the National Institutes of Health while the House proposes an even larger boost of $6.5 billion. Either amount would represent by far the largest increase among the string of multibillion dollar boosts in each of the past six years.

Both bills strongly support the administration's proposal to fund an Advanced Research Projects Agency for Health (ARPA–H) but allocate less than half the $6.5 billion the administration requested for it. They stipulate that the funds are contingent on Congress passing legislation that formally authorizes the agency, but development of authorization legislation for ARPA–H is still at an early stage.

For more information on the federal budget, visit the American Institute of Physics FYI "Budget Tracker" at https://www.aip.org/fyi/federal-science-budget-tracker. ■

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners:

Estee Lauder Companies | **Elkem Materials** | **AEM Canada Group**

To learn about the benefits of ACerS Corporate Partnership, contact Kevin Thompson, Industry Relations Director, at (614) 794-5894 or kthompson@ceramics.org. ■

Central Ohio Section to visit Glass Axis

The Central Ohio Section will visit Glass Axis on Friday, Jan. 14, 2021. Glass Axis is a nonprofit, public-access glass art facility and gallery. Their well-equipped studios serve all forms of glass art, including stained and fused glass, torch and hot glass blowing and sculpting, and neon art. Learn more about Glass Axis at https://www.glassaxis.org.

For forthcoming details, check out the Central Ohio webpage at https://ceramics.org/members/member-communities/sections/central-ohio. ■

Dayton/Cincinnati/Northern Kentucky Section hosts happy hour at Annual Meeting

The Dayton/Cincinnati/Northern Kentucky ACerS Section hosted a successful networking happy hour during the Annual Meeting at MS&T 2021. More than 20 Section members and friends gathered to network and congratulate newly inducted ACerS Fellow (and former Section chair) Emmanuel Boakye. ■

Dayton/Cincinnati/Northern Kentucky Section announces Elevator Pitch Competition

The Dayton/Cincinnati/Northern Kentucky Section announced its first virtual Elevator Pitch Competition for undergraduate and graduate students. Students will submit a one-minute video addressing the impact of ceramics in society (e.g., dissertation work, research project, topic learned in class). The top 10 entries will receive a one-year GGRN membership (graduate students only) and $100 toward a 2022–2023 ACerS conference. Videos will be posted to the Section webpage of ceramics.org.

Rules for submission:

- Maximum video length of 60 seconds
- No slides
- Props allowed
- Creativity is encouraged

Students may download the application form at https://forms.gle/c9Y6GuDKUjKF9SdBA and submit videos to Karen McCurdy at kmccurdy@ceramics.org by **Friday, Jan. 14, 2022.** ■

Spain Chapter cohosts Sustainability in the Ceramic Sector

The Spain Chapter cohosted an information day on "Sustainability in the ceramic sector" on Nov. 4, 2021. Key ongoing initiatives aimed at promoting sustainability in the ceramic sector were presented, as well as several projects funded by the European Union LIFE Program. View the full program at http://descarga.itc.uji.es/infoday-programa.pdf. ■

Spain Chapter cohosts SECV-Zero Emissions Conference on October 4 and 5

The SECV-Zero Emissions-Renewable H2, Energy Vector Conference was held on Oct. 4–5, 2021. Co-organized by the ACerS Spain Chapter, the Spanish Ceramic and Glass Society, and the Institute of Ceramic Technology, the initiative focused on the zero emissions challenge and offered an overview of the most promising technologies in generating, storing, and distributing renewable hydrogen, as well as funding sources for the industrialization of these technologies. Visit the Spain Chapter webpage at https://ceramics.org/spain-chapter for links to recorded talks and posters. ■

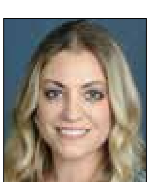
New England Section plans its future

The revitalized New England Section hosted its first event on October 8. Nate Orloff presented a webinar titled "Beyond 5G materials, measurements, and standards." More information on the webinar can be found on the New England webpage at https://ceramics.org/members/member-communities/sections/new-england.

The Section continues to look for leadership and volunteers. Contact Karen McCurdy at kmccurdy@ceramics.org if interested in becoming involved with this newly revitalized Section. ■

Names in the news

Members—Would you like to be included in the Bulletin's Names in the News? Please send a current head shot along with the link to the article to mmartin@ceramics.org. The deadline is the 30th of each month.


Snow

Bryn Snow, HarbisonWalker International director of application technology and CGIF Trustee, received a 2021 STEP Ahead Award from The Manufacturing Institute in Washington, D.C., on Nov. 4, 2021. The award recognizes women in science, technology, engineering, and production who exemplify leadership in their companies.

IN MEMORIAM

Fred Phelps
Peter Smith
Bruce Tuttle

Some detailed obituaries can also be found on the ACerS website, www.ceramics.org/in-memoriam.

more SOCIETY DIVISION SECTION CHAPTER NEWS

Volunteer spotlight

ACerS Volunteer Spotlight profiles a member who demonstrates outstanding service to the Society.

Ohji

Tatsuki Ohji is a Fellow Scientist at the National Institute of Advanced Industrial Science and Technology, Japan. He earned his doctoral degree in inorganic materials engineering from Tokyo Institute of Technology. His research interests include microstructural design and mechanical properties of ceramics, ceramic composites and porous materials, and green manufacturing of advanced ceramic materials and components. He has authored or coauthored more than 360 peer-reviewed papers.

An ACerS Fellow, Ohji is also a Fellow of the ASM International, the American Association for the Advancement of Science, the European Ceramic Society, and the Ceramic Society of Japan. He received many awards, including ACerS' Bridge Building Award, John Jeppson Award, Samuel Geijsbeek PACRIM International Award, and W. David Kingery Award. Currently a Governor of *Acta Materialia Inc.*, Ohji serves on the editorial boards of several international journals, including the *Journal of the American Ceramic Society*.

Ohji is a member of ACerS Engineering Ceramics Division, the Bioceramics Division, and the Energy Materials and Systems Division. Among his contributions to ACerS, he has served as the chair and trustee of the ECD, as an ACerS board member, and as ACerS president (2019–2020).

We extend our deep appreciation to Ohji for his service to our Society!

AWARDS AND DEADLINES

FOR MORE INFORMATION:

ceramics.org/members/awards

Last call for 2022 award nominations

Nominations for most ACerS Society and several Division awards are due **Jan. 15, 2022**. Nominations are encouraged for deserving candidates from groups that have been underrepresented in ACerS awards relative to their participation in the Society, including women, underrepresented minorities, industry scientists and engineers, and international members.

For more information, visit www.ceramics.org/awards or contact Erica Zimmerman at ezimmerman@ceramics.org.

ECD best poster awardees from ICACC 2021

The Engineering Ceramics Division announced the Best Poster awardees from the ICACC 2021 virtual meeting held last January. The awardees will be honored during the plenary session at ICACC 2022 in Daytona Beach, Fla. Congratulations to the authors of these award-winning posters!

2021 Best Poster Awards

First prizes

In situ synchrotron diffraction of $DyPO_4$ pressure-induced phase transformation under variable hydrostaticity
Jai Sharma et al., Colorado School of Mines

Evaluation of mechanical characteristics of GFRP with titanium coating for preventing the ultraviolet degradation
Takenobu Sakai et al., Saitama Industrial Technology Center, Saitama University, Japan

Two-steps reactive cold sintering of geopolymers
Useche dos Santos Inchauspe et al., Industrial Engineering, University of Padova, Italy

Ceramic Tech Chat:

Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the second Wednesday of each month.

In the November episode of Ceramic Tech Chat, Ricardo Castro, professor of materials science and engineering at the University of California, Davis, describes how a jet engine demonstration piqued his interest in ceramics, why he uses superheroes to teach students about materials, and discusses the importance of open-access publishing to facilitating science research.

Check out a preview from his episode, which features Castro explaining how he came up with the idea for the Engineering Superheroes project.

"So, talking about ceramics or metals or calculus or whatever you do that is hard core or difficult to understand will automatically create some barriers. And then you start reading the literature about education and then you see those guys saying that it's very challenging to have classrooms and classes that are longer than one hour because the students lose attention. And then I say, 'Wait a minute. I just came from the theater, and I was sitting for three hours watching Infinity War or End Game, and nobody was distracted. Like, people were really, really focused.' ... So, I don't think there is a problem with the attention spans of students. I think ... a combination of entertainment and education can be the key to actually engage students at a young age into solving complex problems."

Listen to Castro's whole interview—and all of our other Ceramic Tech Chat episodes—at http://ceramictechchat.ceramics.org/974767. ■

Second prizes

Multimaterial 3D printing of solid oxide fuel cells
Natalia Kostretsova et al., Catalonia Institute for Energy Research, Spain

Nanofibrous zirconia highly porous ceramic structures
Riley Yager et al., University of Alabama at Birmingham

Third prize

Synthesis and characterization of steel-MAX composites
Abdulrahman Aldossary et al., University of North Dakota

Trustee awards

Electrical properties of 8YSZ-ScCeSZ composite
Talita Gishitomi Fujimoto et al., Energy and Nuclear Research Institute-IPEN-CNEN/SP, Brazil

Red clay-based ceramic coating on stainless steel fistula needle by electrophoretic deposition
Ivyleen C. Bernardo-Arugay et al., Materials and Resources Engineering and Technology, Mindanao State University-Iligan Institute of Technology, Philippines

Stress analysis in composite laminates with alternating materials in the longitudinal direction: A variational approach
Shinji Ogihara et al., Department of Mechanical Engineering, Tokyo University of Science, Japan ■

more AWARDS AND DEADLINES

2020–2021 Global Ambassador awardees

The Global Ambassador Program recognizes dedicated ACerS volunteers worldwide who demonstrate exceptional leadership and/or service that benefits the Society, its members, and the global ceramics and glass community.

ACerS 2020–2021 President Dana Goski selected the following eight volunteers for the Global Ambassador Award.

Mario Affatigato, Coe College

Katalin Balázsi, Centre for Energy Research, Centre of Excellence of Hungarian Academy of Sciences

James Hemrick, Oak Ridge National Laboratory

Stephen Houseman, Harrop Industries, LLC

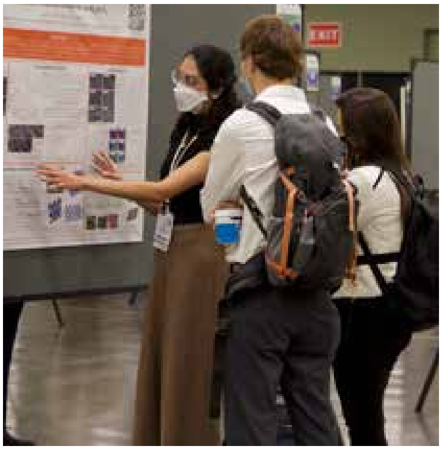
Yutai Katoh, Oak Ridge National Laboratory

Mihails Kusnezoff, Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Hui-suk Yun, Korea Institute of Materials Science

Jie Zhang, Chinese Academy of Sciences ■

STUDENTS AND OUTREACH



Register for Winter Workshop 2022

The 2022 ACerS Winter Workshop will be held Jan. 21–23, 2022 in Daytona Beach, Fla. Noted scientists will share progress and perspective in key areas of ceramics research, from additive manufacturing to ceramics for space applications.

Participation is limited, so register today at https://ceramics.org/winter-workshop-2022. ■

Students and young professionals going to EMA22 or ICACC22: Plan to attend these events

Student and young professional activities are being offered at the Electronic Materials and Applications (EMA 2022) conference and the 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2022).

EMA 2022 student events

https://ceramics.org/student-events-ema22

- Industry Panel for Student and Young Professionals (organized by ACerS PCSA), Wednesday, Jan. 19, 12:30–2 p.m.
- ACerS Journal Workshop, Thursday, Jan. 20, 12:30–2 p.m.
- Student and Young Professional Networking Mixer, Thursday, Jan. 20, 5:30–6:30 p.m.

ICACC 2022 student events

https://ceramics.org/student-events-icacc22

- Student and Young Professional Networking Mixer, Monday, Jan. 24, 7:30–9 p.m.
- ACerS Journal Workshop, date and time to be determined
- Shot Glass Competition (organized by ACerS PCSA), Tuesday, Jan.25, 6:45–8 p.m.
- Student and Industry Failure Trials (SIFT) Competition (organized by ACerS PCSA), Wednesday, Jan. 26, 5:30–7:30 p.m.
- Industry Panel for Student and Young Professionals (organized by ACerS PCSA), Wednesday, Jan. 26.
- We hope to offer the Lunch with a Pro program again this year. Updated information will be shared via email and social media.
- Share your comments, photos, videos, selfies, and other shareworthy content on Facebook or Twitter using the hashtag **#ICACC22**, and you will be entered to win a $50 gift card! We will be giving away one per day (January 24-26). ■

FOR MORE INFORMATION:

ceramics.org/students

National Mentoring Month and the future of ACerS mentor programs

Mentor Jorgen Rufner and mentee Victoria Christensen at ACerS Annual Meeting at MS&T19 in Portland, Ore.

It seems perfectly fitting that January is National Mentoring Month. Historically, January has signified a new beginning. At the dawn of a new year, we set ourselves up for a fresh start—which makes it a great time to kick off ACerS mentor programs for the 2021–2022 term.

ACerS mentor programs aim to connect members in an impactful way to help them grow personally and professionally. The programs are designed to equip participants with the insight, tools, and connections necessary to make a lasting impact in their future career. Many mentor program participants choose to return each year to take on a new mentee, and/or continue with an existing mentee. The External Partnerships Committee of the President's Council of Student Advisors has created and run a student mentor program since October 2018. At that time, the program started out with 14 mentor pairs. These original pairs continued to grow and evolve the program, and the 2020–21 term garnered more than 50 mentor pairs in the program.

The Education and Professional Development Council (EPDC) put together the new EPDC Mentor Program Subcommittee to manage and create new programs based upon the framework of the PCSA's Student Mentor Program.

The newly created Faculty Mentor Program came about as a confluence of the new subcommittee and the goals of the Emerging Ceramic & Glass Faculty Task Force, which was formed in 2020 and led by Elizabeth Dickey, 2021–2022 ACerS president.

The goal is to continue growing the mentor programs offered. Predicated on the outcome of the new faculty-focused program, the EPDC subcommittee will aim to create a program for the 2022–2023 term with a focus on industry.

Visit www.ceramics.org/mentorship to stay up to date on new program offerings and the opening of the 2022–2023 mentor program term. Contact Yolanda Natividad, ACerS member engagement manager, at ynatividad@ceramics.org with questions. ■

Career resources at your fingertips

Looking for some guidance to help begin or advance your career? You can connect with expert career coaches and resume writers who can answer your questions and help prepare you for your job search by accessing the online Ceramic and Glass Career Center's Career Resource Center.

The Career Resource Center also provides:

- ACCESS to relevant career content to assist with career development,
- MATERIALS to help you prepare for job interviews,
- JOB searching tips,
- ADVICE on how to efficiently change careers.

Take advantage of these valuable career resources and upload your resume today at https://careers.ceramics.org. ■

Apply anytime for a PACK Fellowship

PACK is a National Science Foundation funded international research fellowship opportunity for graduate students (U.S. citizens or permanent residents only) to conduct research at the University of Kiel, Germany.

Applications are accepted year-round, and applicants can be from any science or engineering discipline. Review the PACK website at http://packfellowship.org for more information and to apply. ■

more STUDENTS AND OUTREACH

Credit: ACerS

Pictured above: Iowa State University students strike an Arnold Schwarzenegger pose outside the Columbus Convention Center during ACerS Annual Meeting at MS&T21.

ACerS GGRN for young ceramic and glass researchers

ACerS Global Graduate Research Network puts you on a path toward post-graduate success with professional and career development programs aimed at graduate students whose primary interests are ceramics and glass. Learn more at www.ceramics.org/ggrn or contact Yolanda Natividad at ynatividad@ceramics.org. ■

Semiconductor chips: Applications and impact of shortage

By BCC Publishing Staff

The global market for semiconductor chips was valued at $341.5 billion in 2020 and is estimated to grow at a compound annual growth rate of 7.8% to reach $553.6 billion by 2026.

Semiconductors, also known as integrated circuits or microchips, are a critical component of a variety of electronic devices. Silicon is currently the material most widely used to make semiconductor chips because it is an excellent conductor of electricity.

Over the last few years, semiconductors have become an integral component in emergent sectors, such as artificial intelligence, quantum computing, and enhanced wireless networks, including 5G. Growth in these sectors is expected to compensate for a stagnant market in consumer electronics, which is reaching a maturity stage.

A global semiconductor shortage began in 2020, when the COVID-19 pandemic ravaged the majority of the world's countries. The global chip shortage is largely affected by

- **Sudden demand for consumer electronics.** During the first wave of the pandemic, a larger number of consumers were involved in purchasing PCs, monitors, and other peripherals due to new work-from-home and homeschooling requirements. Demand for home entertainment gadgets, such as game consoles, televisions, smartphones, and tablets, also surged dramatically in the final quarter of 2020.
- **Disruption in supply chain caused by the pandemic.** Government lockdowns and COVID-19 regulations halted the manufacturing of semiconductor chips for nearly half of 2020. When production resumed, semiconductor companies were forced to adapt to rising pressure from a variety of sectors, including the unanticipated spike in consumer electronics sales and increased demand in the automotive industry as consumers moved toward personal vehicles to avoid public transportation during the pandemic.
- **Trade wars.** The ongoing trade war between the U.S. and China also contributed to the shortage. In 2018, the Trump administration put 25% tariffs on $34 billion worth of Chinese imports, including semiconductors, and in 2019, the Trump administration prohibited the sale of American-made components, including semiconductors, to Chinese telecom giant Huawei. These policies acted as a deterrent for producers to manufacture chips in the U.S., Huawei began acquiring processors from nonbanned manufacturers, and China increased its own chip production and began stockpiling. Also, an ongoing trade war between Japan and South Korea has contributed to the shortage as well.
- **Drought in Taiwan.** Taiwan is home to some of the world's largest and most advanced high-tech semiconductor foundries. Over the last year, Taiwan has experienced its worst drought in 56 years because of below-average rainfall. As a result, water scarcity became a significant issue in 2021 for Taiwan's technology industry, which requires vast amounts of ultrapure water to avoid contamination of electronic equipment.
- **Industrial accidents.** Several industrial accidents also contributed to the current global semiconductor chip shortage. For instance, in March 2021, a fire broke out at Renesas, one of the Japan's leading manufacturers of silicon wafers. The facility was eventually reopened, but only after a three-month hiatus that significantly affected its production. In February 2021, a fierce winter storm closed computer-chip facilities in Texas. China's ongoing power shortage is putting a further dent in small and medium-sized companies semiconductor production this year.

The current consensus is that the semiconductor scarcity will last until at least until the end of 2022.

Table 1. Global market for semiconductor chips, by application, through 2026 ($ billions)

Application	2019	2020	2021	2026	CAGR % (2021–2026)
Communications	109.6	107.1	119.9	180.9	8.6
Computing	94.8	111.3	123.3	174.4	7.2
Consumer	43.7	47.1	53.1	80.4	8.7
Automotive	40.5	34.5	39.7	57.3	7.6
Industrial	39.2	38.2	41.3	55.7	6.2
Others	3.2	3.3	3.7	4.9	5.8
Total	331.0	341.5	381.0	553.6	7.8

About the author

BCC Publishing Staff provides comprehensive analyses of global market sizing, forecasting, and industry intelligence, covering markets where advances in science and technology are improving the quality, standard, and sustainability of businesses, economies, and lives. Contact the staff at Helia.Jalili@bccresearch.com.

Resource

BCC Publishing Staff, "Semiconductor chips: Applications and impact of shortage" BCC Research Report SMC131A, December 2021. www.bccresearch.com.

research briefs

A new understanding of damage tolerance mechanisms in a MAX phase

Researchers at Texas A&M and Universite Grenoble Alpes in France demonstrated healing of cracks in a MAX phase material at room temperature through a mechanism that the authors describe as "kinking-induced crystallographic rotation and plastic deformation."

MAX phases are atomically layered ceramic materials with the general formula $M_{n+1}AX_n$, where M is a transition metal, A is a metalloid, and X is carbon or nitrogen. The layers are weakly bonded, which leads them to fracture readily.

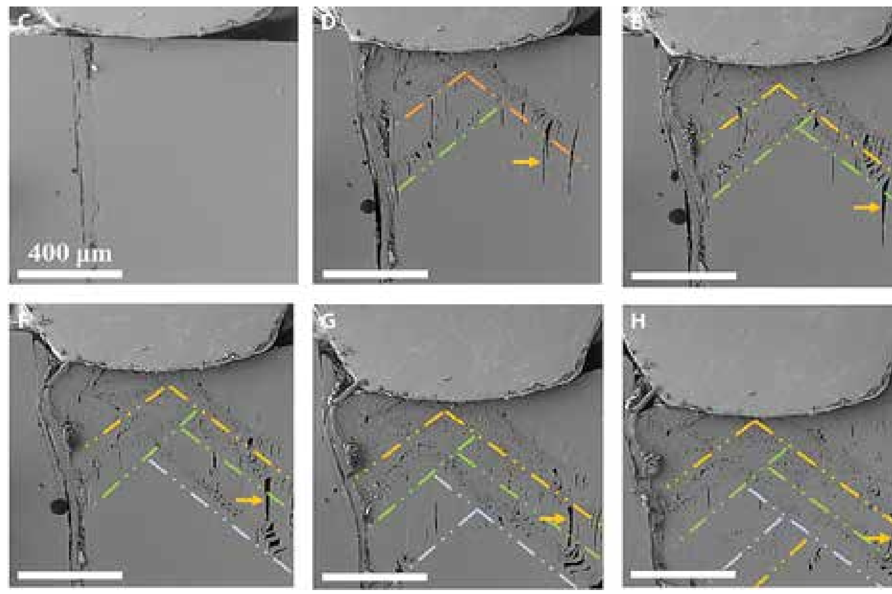
Despite the weakly bonded layers, MAX phases have a surprisingly high damage tolerance. Other atomically layered materials such as graphite, mica, and boron nitride are known to have poor damage tolerance and cleave readily long the weakly bonded planes.

In an *ACerS Bulletin* article in April 2013, Miladin Radovic, professor of materials science and engineering at Texas A&M, and Michel Barsoum, Distinguished Professor at Drexel University, described mechanical properties of MAX phases and the role of dislocations. However, the reason for MAX phases' high damage tolerance remained a mystery—until the new study.

"What we discovered by testing single-crystal MAX phases that became available only recently is amazing as it shows that cracks in individual MAX phase grains can close and heal, thus contributing to the exceptional damage tolerance of MAX phases," Radovic says in an email.

In the new study, the researchers conducted in situ indentation tests in an SEM chamber under freestanding and constrained conditions on a MAX phase Cr_2AlC single crystal. They applied compression along the $\langle 11\bar{2}0 \rangle$ crystallographic direction, which is a known slip system. The constrained test allowed researchers to mimic the effect of neighboring grains in a polycrystalline material.

In the freestanding condition, compression led to Poisson expansion



Crack initiation and healing in a Cr_2AlC MAX phase. SEM images show initiation of cleavage cracks and kinking of ligaments between cracks. The dash-dot-dot lines trace the plastic deformation bands, and the arrow points to the growth and healing of a crack.

perpendicular to the basal plane and encouraged cleavage crack initiation between the weakly bonded layers. Cracks grew slowly underneath the indenter during loading as ligaments between the cracks buckled and rotated, interrupting crack growth. The buckled areas returned to their original configuration on unloading.

Applying compressive load in a constrained environment eliminated the possibility of Poisson expansion, and cleavage cracks did not propagate readily through the sample. Instead, they appeared to be interrupted by "plastic deformation in bands inclined to the indentation axis," the authors write.

Continued loading led to more cracks and more plastic deformation bands. The researchers explain that the plastic deformation bands are actually kink bands, and the reorientation process is effectively a polycrystallization process. On removal from the fixture, no large cracks were detected in the deformed sample.

"This [experiment] suggests that the crack closure is not elastic, but the cracks are physically healed during loading; otherwise, relaxation of the compressive stress that built up normal to the basal planes would have caused further crack opening upon unloading," the researchers write.

Coauthor and Texas A&M associate professor Ankit Srivastava notes that this discovery may extend beyond MAX phases.

"Kinking is not unique to MAX phases and has been observed in a variety of other atomically layered ceramic materials, and thus, it is reasonable to assume that the damage tolerance of many of these ceramics may also be enhanced by carefully designing microstructures to promote extensive kinking and crack healing," he says in an email.

The open-access paper, published in *Science Advances*, is "Room temperature crack-healing in an atomically layered ternary carbide" (DOI: 10.1126/sciadv.abg2549). ■

Exploding samples reveal new insights into shape memory ceramics

An international team of researchers led by the University of Minnesota Twin Cities and Kiel University in Germany stumbled upon a seemingly paradoxical result that reveals new insights into reversible transformations in shape memory ceramics.

Shape memory materials are materials that can recover their initial shape under the influence of external stimuli, such as temperature, light, moisture, acidity, or electricity. Certain metal alloys were the first materials identified to exhibit the shape memory effect, and researchers have identified a variety of shape memory polymers and polymer composites that exhibit the effect as well.

The shape memory effect is based on the material undergoing a phase change when exposed to external stimuli. In the case of shape memory polymers, the change between a hard phase to soft phase can be achieved through a variety of physical means due to the intrinsic elasticity of polymeric networks. For shape memory alloys, the effect stems from the material having two stable crystal structures: a high temperature-favored austenitic phase and a low temperature-favored (and "yieldable") martensitic phase.

When shape memory alloys undergo transformation from one solid phase to another, they can experience a stressed transition layer that separates the twinned martensite phase from the austenite phase. This stress affects the alloys' ability to reverse the transformation.

To improve reversibility of the solid–solid phase transformation, researchers try to improve the geometric compatibility of the alloy. In other words, they carefully tune the lattice parameters in the alloy to decrease the elastic energy in the transition layer, and thereby improve the alloy's ability to reversibly transform between the two solid phases.

Like alloys, ceramics consist of a crystalline structure and have different stable solid phases. This similarity between alloys and ceramics, particularly zirconia-based ceramics, has led to some success in developing shape memory ceramics by applying the same general strategies used for alloys. For example, a few recent studies improved the phase transformation of various oxide systems by improving the geometric compatibility.

Based on these previous successes, the international research team conducted a systematic search to identify more ceramics that exhibit reversible phase transformations and shape memory behavior based on improving geometric compatibility. They looked at the ceramic system $(Zr/Hf)O_2(YNb)O_4$, which shows the same phase transformations as bulk ZrO_2.

After tuning the lattice parameters to improve the geometric compatability, the researchers tried cooling the ceramic through its tetragonal-to-monoclinic phase transformation at 1,170°C. However, instead of transforming, the polycrystal slowly and steadily fell apart at its grain boundaries (a process the researchers termed weeping) or even explosively disintegrated.

The researchers suggest the behavior is due to the $(Zr/Hf)O_2(YNb)O_4$ system having multiple lattice correspondences, i.e., multiple possibilities for which atoms go where during

Credit: Gu et al., *Nature* (CC BY 4.0)

Screenshot from a video showing the disintegration of a ceramic as it attempts to undergo a tetragonal-to-monoclinic phase transformation.

transformation. They tuned the lattice parameters based on one of these correspondences, which should have made it easier for the material to undergo transformation. However, it instead appeared to have introduced strain elsewhere in the structure, leading to the disintegration.

The researchers then tried modifying the structure based on an equidistance condition, which takes into account multiple correspondences. This time, the ceramic did demonstrate a reversible transformation.

"While these behaviours seem at first to contradict accepted principles, in fact they serve to widen the set of theory-driven tools applicable in the search for reversible transformations in ceramics," the researchers write. "Our work also highlights the subtle interplay of multiple transformation correspondences."

The paper, published in *Nature*, is "Exploding and weeping ceramics" (DOI: 10.1038/s41586-021-03975-5). ■

Beyond soft tissue—effect of low-level laser therapy on osseointegration of implants

Researchers in Brazil and Ecuador explored whether low-level laser therapy (LLLT) can improve osseointegration of bone implants.

LLLT, or photobiomodulation, is a relatively new and fast-growing technology used to promote tissue healing and pain relief in a broad spectrum of soft tissue injuries and diseases. While LLLT is mostly used to treat soft tissue ailments, some studies have investigated the potential of LLLT to treat bone defects as well.

Last year, the researchers in Brazil and Ecuador published a study supporting the hypothesis that LLLT induces a high degree of osseointegration, or the process by which an implant fuses with the surrounding bone. However, the success of LLLT is highly dependent on a large number of parameters, including wavelength, fluence, power density, pulse structure, and timing of the applied light. As such, the researchers' goal for their new study was to begin determining optimal parameters to achieve best results.

They used the same osteoconductive bone substitutes used in last year's study: deproteinized bovine bone (DBB) and biphasic ceramics based on hydroxyapatite and β-tricalcium phosphate (HA/TCP). They used these materials to treat bone defects in three-month-old brown rats.

Results from histometric, tomographic, and biomechanical analyses revealed that LLLT improves osseointegration in areas grafted with DBB and HA/TCP. This effect was greater when the irradiation protocol was used only after implant placement, in contrast to use of LLLT after both the graft procedure and implant placement, which demonstrated limited improvement compared to nonirradiated groups. A better pattern of osseointegration with implants placed in the DBB grafted areas rather than HA/TCP grafted areas was noted as well.

Credit: pete beard, Flickr (CC BY 2.0)

Researchers in Brazil and Ecuador used brown rats (Rattus norvegicus) to investigate the effect of low-level laser therapy on osseointegration of implants.

The researchers say future studies will need to compare the effects of using a red laser versus infrared, which was used in this study, and clinical studies are also required.

The open-access paper, published in *Journal of Applied Oral Science*, is "Effect of different low-level intensity laser therapy (LLLT) irradiation protocols on the osseointegration of implants placed in grafted areas" (DOI: 10.1590/1678-7757-2020-0647). ■

Speeding detection of disease—three groups present novel sensors for COVID-19 diagnosis

Frequent testing is crucial to early detection and containment of COVID-19. Testing is much more accessible now than it was at the start of the pandemic, especially in many European countries. For people in the United States, however, rapid tests can still be challenging to secure, in part due to regulations that make bringing new tests to market difficult.

Fortunately, barriers to commercialization are not stopping scientists from continuing to develop new and improved methods for rapid testing, such as the authors of the three recent studies below.

Breathing life into a novel COVID-19 detector

Breathalyzers measure various chemical compounds in a person's breath. Estimating someone's blood alcohol level is a common application of breathalyzers, but breathalyzers can also be used to detect different diseases.

Pelagia-Irene (Perena) Gouma, Edward Orton, Jr., Chair in Ceramic Engineering and director of the Advanced Ceramics Research Laboratory at the Ohio State University, began exploring use of breathalyzers for medical diagnostics in 2003. When the pandemic started, Gouma's team started developing a breathalyzer capable of detecting COVID-19.

Last year, Gouma's team started human and animal testing of their breathalyzer. Now, the researchers have published an open-access paper in *PLOS One* detailing the results of tests conducted in the Ohio State University hospital system. They compared the breath profiles of patients with and without active COVID-19 respiratory infection, and the breathalyzer detected high exhaled nitric oxide concentration with a distinctive pattern for patients with active COVID-19.

"This is the first work to our knowledge to demonstrate use of a nanosensor breathalyzer system to detect a viral infection from exhaled 'breathe prints,'" they conclude.

The open-access paper, published in *PLOS One*, is "Exhaled nitric oxide detection for diagnosis of COVID-19 in critically ill patients" (DOI: 10.1371/journal.pone.0257644).

Two carbon allotropes lead to sensors that detect SARS-CoV-2 and its proteins

While the breathalyzer determines COVID-19 diagnosis based on changes to the chemical makeup of a person's breath caused by the disease, the other two recently developed sensors instead base diagnosis on direct detection of SARS-CoV-2, the coronavirus that causes COVID-19, and its proteins.

The first study is by researchers at Fudan University in China. They used graphene to develop a field-effect transistor that detects SARS-CoV-2 RNA.

Among COVID-19 diagnostic methods, reverse transcription polymerase chain reaction (RT-PCR) tests are considered a gold standard. These tests detect the RNA of SARS-CoV-2, even if the virus is present in extremely small amounts. However, these tests normally require extraction and amplification procedures to reach a final diagnosis, which requires specialized facilities and time.

The new transistor developed by the Fudan University researchers detects SARS-CoV-2 RNA as well, through Y-shaped fragments of DNA located on the transistor that target two genes encoded in the RNA genome of SARS-CoV-2. Unlike the RT-PCR tests, however, the transistor does not require extraction or amplification procedures, thus streamlining the diagnosis process.

In a *C&EN* article, graduate student and first author Derong Kong says, "The detection limit of our method is also very low, detecting about three molecules of SARS-CoV-2 RNA in 100 μL of solution." That limit of detection makes the test 20 times as sensitive as the standard for quantitative RT-PCR assays set by the U.S. Centers for Disease Control and Prevention, according to the article.

The paper, published in *Journal of the American Chemical Society*, is "Direct SARS-CoV-2 nucleic acid detection by Y-shaped DNA dual-probe transistor assay" (DOI: 10.1021/jacs.1c06325).

The second study is by researchers at the Massachusetts Institute of Technology. They used carbon nanotubes to develop a sensor that selectively detects certain viral proteins of SARS-CoV-2.

When SARS-CoV-2 infects a host cell, it deploys a "translation-ready" RNA molecule that harnesses protein synthesis machinery of the host to express a set of viral proteins crucial for replication. The MIT researchers chose to use an approach called corona phase molecular recognition (CoPhMoRe) to detect these viral proteins. As explained in the press release, CoPhMoRe takes advantage of a phenomenon that occurs when certain types of polymers bind to a nanoparticle.

"Known as amphiphilic polymers, these molecules have hydrophobic regions that latch onto the tubes like anchors and hydrophilic regions that form a series of loops extending away from the tubes. Those loops form a layer called a corona surrounding the nanotube. Depending on the arrangement of the loops, different types of target molecules can wedge into the spaces between the loops, and this binding of the target alters the intensity or peak wavelength of fluorescence produced by the carbon nanotube," the press release explains.

The researchers wrapped carbon nanotubes in different polymers that were chosen based on their response to the nucleocapsid and spike proteins of SARS-CoV-2. They then incorporated these sensors into a prototype device with a fiber optic tip that can detect fluorescence changes in the sample in real time, thus eliminating the need to send the sample to a lab.

Credit: CDC, Unsplash

A public health officer assesses a sick traveler who had just arrived at the Los Angeles International Airport from another country.

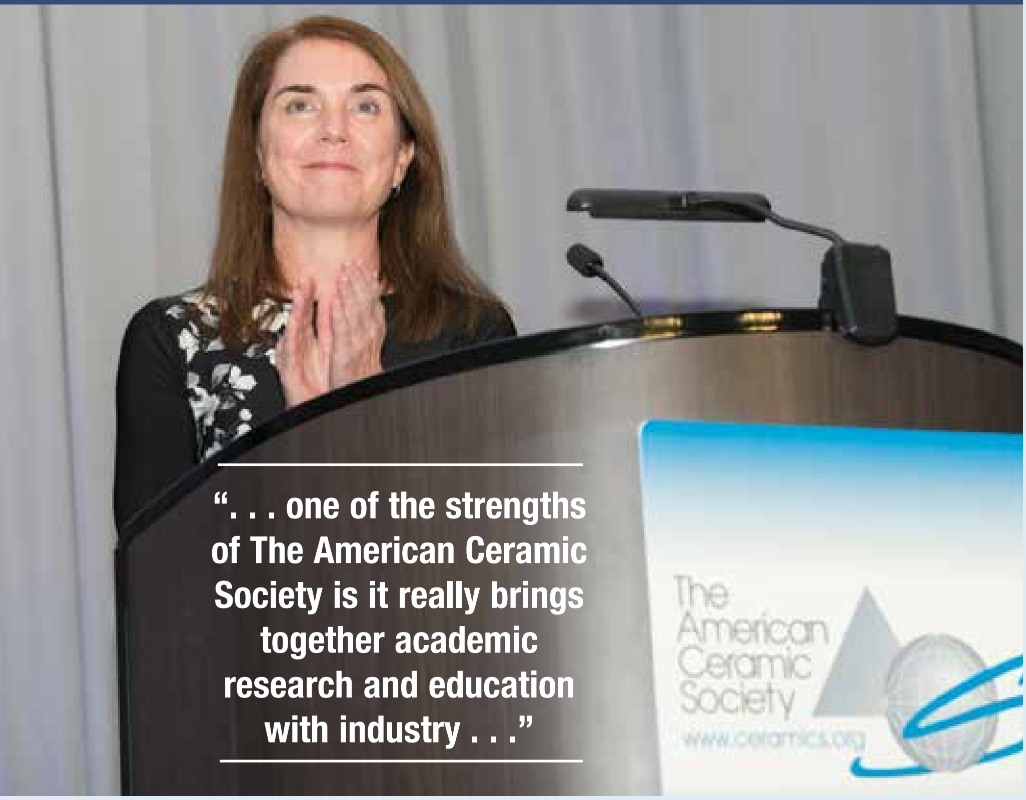
The sensor produced a result within about 5 minutes and detected concentrations as low as 2.4 picograms of viral protein per milliliter of sample. In addition, the sensor detected the SARS-CoV-2 nucleocapsid protein (but not the spike protein) when it was dissolved in saliva, which is difficult to do because "saliva contains sticky carbohydrate and digestive enzyme molecules that interfere with protein detection," the press release explains.

The paper, published in *Analytical Chemistry*, is "Antibody-free rapid detection of SARS-CoV-2 proteins using corona phase molecular recognition to accelerate development time" (DOI: 10.1021/acs.analchem.1c02889). ■

Meet ACerS president Beth Dickey

By Eileen De Guire

(Credit: ACerS)



"... one of the strengths of The American Ceramic Society is it really brings together academic research and education with industry ..."

Kentucky—one of the four Commonwealth states in the United States—is renowned for its bluegrass music, bourbon production, and horse racing and raising. It is also the state that produced one of the world's premier electron microscopists and this year's ACerS president, Elizabeth "Beth" Dickey, although she did not come from a physical sciences background.

"My father trained horses, where I grew up in central Kentucky, and that was a big part of my life growing up," says Dickey. "My mother was in nursing, so actually engineering is pretty new to my family."

The University of Kentucky conducted outreach programs through the physics and chemistry departments of her public high school, and, being the late 1980s, the university brought a high-temperature ceramic superconductor levitation demonstration. Intrigued, Dickey enrolled at the University of Kentucky and earned her B.S. materials in science and engineering.

The seeds of a career in ceramic materials science firmly took root during an undergraduate summer internship at Oak Ridge National Laboratory in the High Temperature Materials Lab.

Dickey recalls, "There was a very sizable ceramics group at that time, and ... was focused on high-temperature ceramics for ceramic engines and those sorts of things. That was my first entry point."

She entered a Ph.D. program at Northwestern University, where her research focused on ceramic composites and characterizing the interfaces, which led to her expertise in electron microscopy.

"Electron microscopy, specifically transmission electron microscopy, lends itself well to studying things like grain boundary and interfacial phenomena. That's where I marry my expertise in microscopy with ceramic science. A lot of what I do is very much focused on defects in materials," she says.

Today, Dickey is Teddy & Wilton Hawkins Distinguished Professor and department head of materials science and engineering at Carnegie Mellon University in Pittsburgh, Pa.

Dickey joined ACerS as a graduate student and belongs to the Basic Science Division, Electronics Division, and Engineering Ceramics Division. She served in the BSD leadership and the Board of Directors, and is an editor of the *Journal of the American Ceramic Society*.

Dickey's first goal as ACerS president is to steer a steady course through the remaining pandemic.

"We've done a great job over the last year, and the Society is extremely healthy, but I think we're still learning from that experience and probably still going to be reacting to certain situations that come up through the year that we can't predict," she says.

The next big goal is to begin implementing the just-developed strategic plan and monitoring its progress.

"We're going to think a lot over the next couple of months about connecting with our Divisional leaders and our Section leaders on how to implement the strategic plan, and then think about what data we want to monitor to assess how effective we're being in the strategic plan," she says.

One of the pillar goals in the strategic plan is to increase membership and member engagement, and Dickey takes a holistic view.

"I think one of the strengths of The American Ceramic Society is it really brings together academic research and education with industry, and it's a super important interface between those two communities. Meeting the needs of industry [is important], but also calling on industry to have them play a role in mentoring our students or young professionals and being involved in their professional development," she says.

Dickey will continue the Society's work to expand its global culture of diversity and inclusion, and to ensure that best practices are integrated throughout the Society's structure. That will include continuing to seek partnerships with minority-serving organizations and institutions.

Dickey has two adult children, and in her free time likes to bike, hike, and spend time outdoors. And the saddle still beckons.

"Sometimes when I visit home in Kentucky, I will get a chance to ride a horse, and that connection with animals is important," she says. ■

ACerS holds 123rd ANNUAL BUSINESS MEETING in Columbus Ohio

By Lisa McDonald

Following a virtual meeting in 2020, this year The American Ceramic Society held its 123rd Annual Business Meeting in-person on Monday, Oct. 18, during ACerS Annual Meeting at MS&T21 in Columbus, Ohio. ACerS Annual Meeting at MS&T brings together members from the whole Society as the meeting's technical content spans all aspects of ceramic and glass science, from refractories and aerospace to bioceramics and more.

At the Annual Business Meeting, the ACerS president reports on the state of the Society, and the new president outlines plans for the coming year. President Dana Goski summarized the Society's 2020–2021 accomplishments, including the completion of a new strategic plan, which will guide the Society for the next few years. (Learn more about the strategic plan in the December episode of Ceramic Tech Chat at https://ceramictechchat.ceramics.org).

Treasurer Stephen Houseman reported that the Society weathered the COVID-19 pandemic well and its assets remain "tremendously strong." New officers were sworn-in, and out-going officers were recognized and thanked for their service. Incoming president Beth Dickey outlined her vision and goals for her year as president (see details on previous page). During her introductory speech, Dickey noted that she looks forward to begin implementing ACerS' strategic plan during her tenure.

Because the Annual Awards Banquet could not take place in person last year, ACerS staff gathered 2020 awardees onstage during the 2021 Awards Banquet for a photo op. This year's awardees, which include 17 members elevated to Fellow and three members awarded the distinction of Distinguished Life Member, then came onstage to accept their awards.

Credit: ACerS

Outgoing ACerS president Dana Goski, left, hands the ceramic gavel to incoming ACerS president Beth Dickey during the 123rd Annual Business Meeting on Oct. 18, 2021.

In addition to the Annual Business Meeting, other events that provide updates on different parts of the Society took place both in-person and virtually, including meetings of the Board of Directors, Division executive committee and business meetings, and meetings of ACerS working committees and subcommittees. The Society's student leadership group, the President's Council of Student Advisors, also held its annual meeting. This year PCSA includes 44 students from 28 universities, representing eight countries.

View pictures from ACerS 123rd Annual Business Meeting at https://bit.ly/MST-21photos.

ACerS 124th Annual Meeting at MS&T22 will take place Oct. 9–13, 2022, in Pittsburgh, Pa. ■

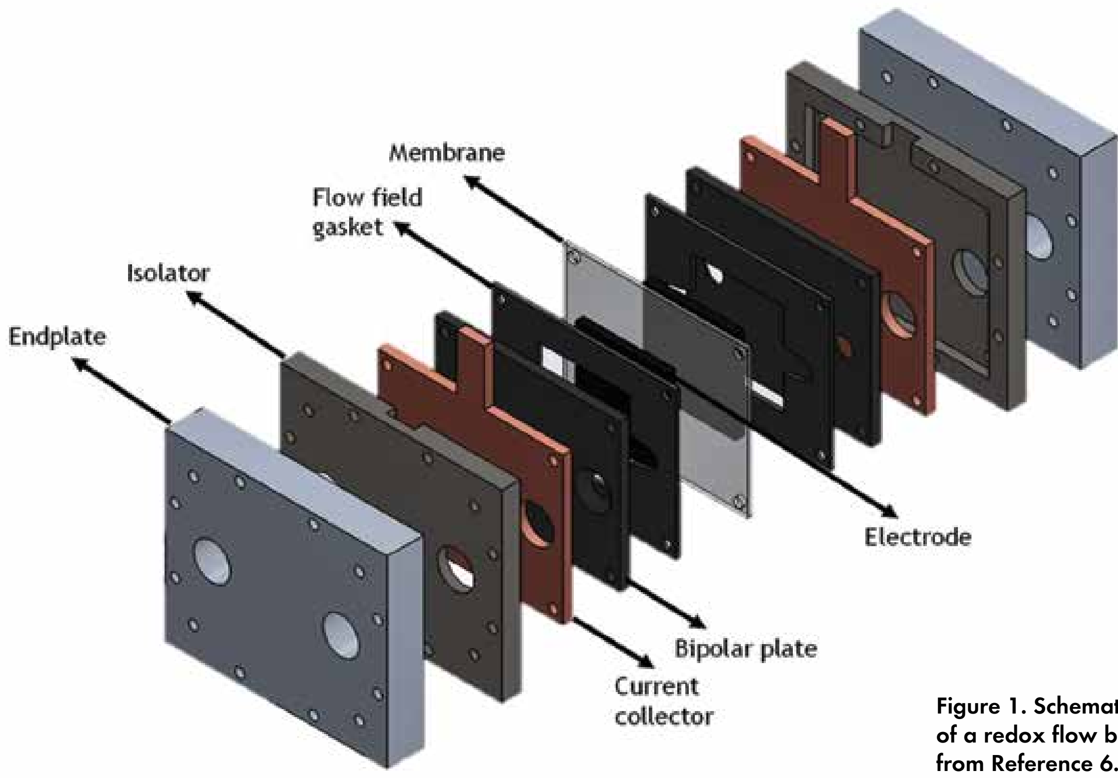


Figure 1. Schematic of the components of a redox flow battery cell. Reproduced from Reference 6.

Flow batteries and energy storage—a new market for ceramics

By Richard Clark

Demand for energy storage technologies is driving dramatic growth in the redox flow battery market, and with it opportunities for the ceramics community.

Redox flow batteries belong to a large and growing group of devices designed for energy storage applications.

Although their origins trace back to a zinc/chlorine flow battery used to power an airship in 1884,[1] rapid, systematic growth in the redox flow battery market has only been apparent within the past decade.

To understand the reasons for this growth and the concurrent opportunities for the ceramics community, it is important to understand several related areas: the energy storage market and its segmentation; the technology behind flow batteries and how it compares to alternatives; and the challenges that need to be addressed to make flow batteries cost-competitive in the market segments where they have an advantage over alternatives.

The energy storage market and the opportunity for redox flow batteries

Widely misunderstood, the energy storage market is highly segmented, with the characteristics required for a given application (primarily discharge time and system power required) having a huge impact on the relative importance of cost. Complicating this market further is the fact that the classification and naming of the segments is not uniform, making comparison of information from multiple sources challenging.

At the top level, the primary categories for energy storage are transportation (mainly electric vehicles) and stationary. While conceptually redox flow batteries can be used for both, practically the only application of note is stationary storage (unless airships make an unexpected comeback) because of the low volumetric energy density of redox flow batteries compared to other technologies, especially the ubiquitous lithium-ion batteries.

Subdivisions for stationary energy storage are generally described by the services they provide as an alternative to conventional grid supply.[2] These subdivisions are (on-grid) regulation, arbitrage, back-up and reserves, black start, investment deferral, and (off-grid) independent power supply. These subdivisions are variously related to generation, transmission, and distribution as well as end-user markets (residential, commercial, and industrial).

Several competing technologies exist for each of the stationary storage market segments, which are categorized as electrochemical (batteries and supercapacitors), thermal (molten salt), and mechanical (flywheels, compressed air, and pumped storage hydropower), although the specific requirements of each segment preclude all technologies from competing for the entire market. Pumped storage hydropower (PSH) is dominant in the overall space: as of mid-2020, 164 GW of PSH is operational, equivalent to an estimated energy in excess of 17 TWh, with an additional 124 GW in various stages of realization.[3] The remaining competition in terms of major market scale is increasingly moving toward lithium-ion and redox flow batteries.

For redox flow batteries, 2021 global sales are projected to reach 350 MWh, with revenue at US$270 million. However, BloombergNEF predicts that redox flow batteries could compete with lithium-ion batteries for up to 46% (69 GWh) of the total capacity (150 GWh) required for grid-related stationary energy storage in 2030 (defined as being the segment which would be otherwise addressed by lithium-ion batteries).[3]

In this analysis, redox flow batteries were assumed to have an average system duration of four hours, which makes them particularly favorable for arbitrage (storing energy when the price of electricity is low and releasing it on the grid when high) and peaking capacity (provision of supply to meet the maximum demand of the system, including back-up and reserves and investment deferral applications). If the system duration can be modified significantly from this value, with appropriate capital and operational economics, then the size of the potential market for redox flow batteries will accordingly increase.

Particularly relevant to redox flow batteries, one of the main drivers behind the growth of the stationary energy storage market is the increasing replacement of fossil fuels with renewable energy sources (most notably wind and solar), which are intermittent and hence not directly coherent with demand. The economics of redox flow batteries are well suited to the relatively long durations required to address this imbalance. They also offer additional benefits such as a high level of safety, long maintenance-free lifecycles, and intrinsic modularity, in that power and energy are decoupled, facilitating customization. In many cases, sustainability issues are also addressed because the chemistries of choice are derived from widely available resources and materials can be readily reused.

A more detailed comparison of redox flow batteries with lithium-ion batteries is provided in Table 1.[4] By necessity, this table is generalized, and there are exceptions in some cases. Sustainability is not included as a category, mainly because the diversity of chemistries used in redox flow batteries preclude generalization. However, there are advantages with many of the more popular types, and it is likely to be an increasingly important consideration in the future.

The technology behind redox flow batteries

A redox flow battery is an electrochemical device that uses the potential difference between a set of redox couples, typically solution-based, to transform electrical energy into stored chemical energy and vice versa.[5] At the most basic level, there are two tanks containing electrolyte connected to a stack of cells where the redox reactions occur. For a single-cell system, a cell would include two current collectors, two bipolar plates, two electrodes, and one membrane, although there are variations on this setup. Cells are usually stacked, so a pair of current collectors would be used for the full stack and bipolar plates would be the components between cells. A schematic of a single cell arrangement is shown in Figure 1.

There are a wide variety of systems encapsulated by the general definition, including inorganic aqueous, organic aqueous, and nonaqueous, and the definition is frequently broadened to include membrane-less, metal-air, semi-

Table 1. Comparison of redox flow batteries with lithium-ion batteries. Adapted from Reference 4. Credit: Daggett

Characteristic	Redox flow batteries (RFB)	Lithium-ion batteries (LIB)
Cycle life	Greater than LIB (e.g., 5x)	Less than RFB
Self-discharge	Near zero	Low
Decoupled energy and power	Feature of most RFB types noted	Not possible
Risk of fire / thermal runaway	Very low / zero	Flammable electrolyte
Safe servicing	Servicing is possible	Cannot discharge and service
Simple monitoring and controls	Cell balancing only for hybrid systems (described below)	Cell balancing required
Accurate measurement of state of charge	Can be done directly	Via voltage/current under load
Complexity of balance of plant	Relatively complex	Liquid-cooled systems complex
Gravimetric energy density	Very low compared to LIB	Much higher than RFB (e.g., 10x)
Volumetric energy density	Very low compared to LIB	Much higher than RFB (e.g., 10x)
Round-trip efficiency	Less than LIB, especially dc	Greater than RFB (e.g., 5 to 10%)
Market penetration	Much less than LIB	Much greater than RFB
Diversity of applications	Many fewer than LIB	Many more than RFB
Cost per kWh	Currently greater than LIB	Currently less than RFB

Green = better option

Flow batteries and energy storage—a new market for ceramics

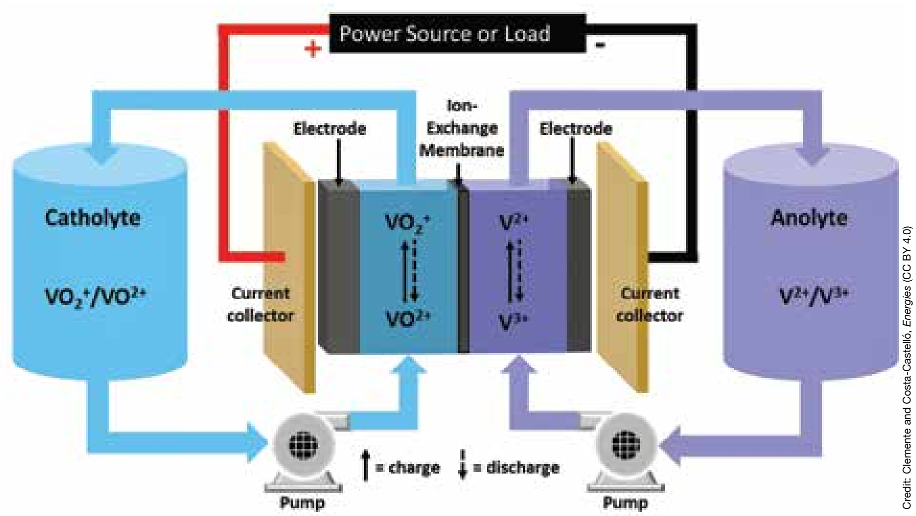


Figure 2. Schematic of an all-vanadium redox flow battery. Adapted from Reference 8.

Table 2. Comparison of types of redox flow battery versus inorganic aqueous systems.
Credit: Clark

System	Proposed differentiation	Example
Inorganic aqueous	Baseline	All-vanadium (VRFB)
Organic aqueous	Abundant precursors, lower cost	Quinone-bromide
Nonaqueous	Improved energy density	All-copper (acetonitrile solvent)
Membrane-less	Lower cost without ion-exchange membrane	Hydrogen-bromine
Metal-air	Improved energy density, lower cost	Zinc-air
Semi-solid (slurry)	No electrolyte solubility limitations	Lithium iron phosphate (LFP)
Electroplated (hybrid)	Improved energy density, lower cost	Zinc-bromine (ZBFB)

solid (slurry), and electroplated redox flow batteries. The latter systems are also termed hybrid redox flow batteries because the total energy storage capacity depends on both the stack size and the size of the electrolyte storage reservoirs. So, energy and power are not fully decoupled, in contrast to more "classical" types, where decoupling frequently is portrayed as a defining feature. Table 2 provides a summary and an example of each system.

Readers will appreciate that the technologies are in significantly different states of development, from those currently at laboratory scale, where there are fundamental challenges yet to be overcome, to those which are already launched commercially. Typically, there are multiple chemistries under investigation for each system, and for a given base chemistry, there are alternative systems and approaches. This flexibility offers great opportunities for innovation.

Table 3 provides a summary of the current state of market readiness for the main types of flow battery.[7] With the exponential growth rate of the energy storage market, the market readiness of each battery is likely to change, and it is quite possible that a technology currently in its infancy could become the dominant force within several years.

Table 3. Market readiness for the main types of flow batteries. Adapted from Reference 7.
Credit: IDTechEx

Chemistry	Example system	Market readiness
All-vanadium (VRFB)	Inorganic aqueous	High
Zinc-bromine (ZBFB)	Electroplated (hybrid)	High
All-iron (Fe-RFB)	Electroplated (hybrid) or semi-solid (slurry)	High
Hydrogen-bromine	Membrane-less	Medium
Organic (ORFB)	Organic aqueous	Medium
Iron-chromium	Inorganic aqueous	Low
Polysulfide-bromide (PSB)	Inorganic aqueous	Low
Vanadium-bromide	Inorganic aqueous	Low
Li-ion RFB	Nonaqueous semi-solid (slurry)	Low

Leading commercial redox flow battery systems

All-vanadium redox flow battery (VRFB)

The invention of the all-vanadium redox flow battery (VRFB) is credited to the work of Maria Skyllas-Kazacos and her research team at the University of New South Wales, Australia, in the 1980s. The VRFB electrolyte tanks contain vanadium at four different oxidation states. On the cathode side, vanadium is at +IV (tetravalent) and +V (pentavalent) states within VO^{2+} and VO_2^+, respectively. On the anode side, vanadium is at +II (bivalent) and +III (trivalent) states. Figure 2 shows a general schematic. Typical materials of construction within the cell include graphite (bipolar plates), graphite felt (electrodes), and membranes based on chemically stabilized perfluorosulfonic acid/polytetrafluoroethylene copolymer acid (PFSA/PTFE), such as Chemour's Nafion 212.

By using vanadium on both sides of the membrane, contamination issues with cross-over are effectively eliminated, although self-discharge would still occur should cross-over happen. Eliminating the possibility of cross-over contamination helps provide VRFBs with extended cycle life, typically 15,000 to 20,000 cycles,[9] far above many other chemistries and battery types.

The early work determined suitable, highly reversible redox reactions for vanadium compounds within an aqueous electrolyte containing an appropriate level of sulfuric acid, providing ionic conductivity, and stabilizing the reactions. More recent work at Pacific Northwest National Laboratory determined that using a mixed acid (sulfuric and hydrochloric) within the electrolyte increases the solubility of the vanadium ions and improves the battery performance, increasing the specific energy and expanding the operating temperature range.

A VRFB offers some significant benefits in sustainability.[10] First, it has full lifecycle CO_2 emissions lower than other battery technologies—estimated at 27% to 37% lower than standard lithium-ion batteries. Secondly, vanadium is not consumed and does not degrade in a VRFB—so at end of life for one battery, it can be reused in another battery or used for another application such as in steel alloys. Additionally, although China is the leading country for vanadium mining, vanadium is mined in many other countries as well (most notably Russia, South Africa, and Brazil), unlike with lithium-ion batteries, where the raw material supply is dominated by China.

With the experience gained over the past three decades and the other benefits noted, it is not surprising that VRFBs are leading the way for flow batteries commercially. Bushveld Energy reports that there are 25 or more VRFB companies globally and that in China alone they are tracking about 2 GWh of VRFBs under construction.[10] The largest facility is 200 MW/800 MWh in Dalian, China, installed by Rongke Power.[11] China is expected to install between 30 GWh and 60 GWh of new energy storage capacity by 2030, and a considerable portion of this storage capacity is likely to be VRFB, providing the economics are suitable.

Vanadium is estimated to be 48% of the cost of the manufacturing cost of a VRFB, and spot pricing of the relevant chemicals in 2021 is still about 50% higher than needed for VRFB to have an economic advantage over lithium-ion batteries, although the other benefits such as increased safety may be sufficient.

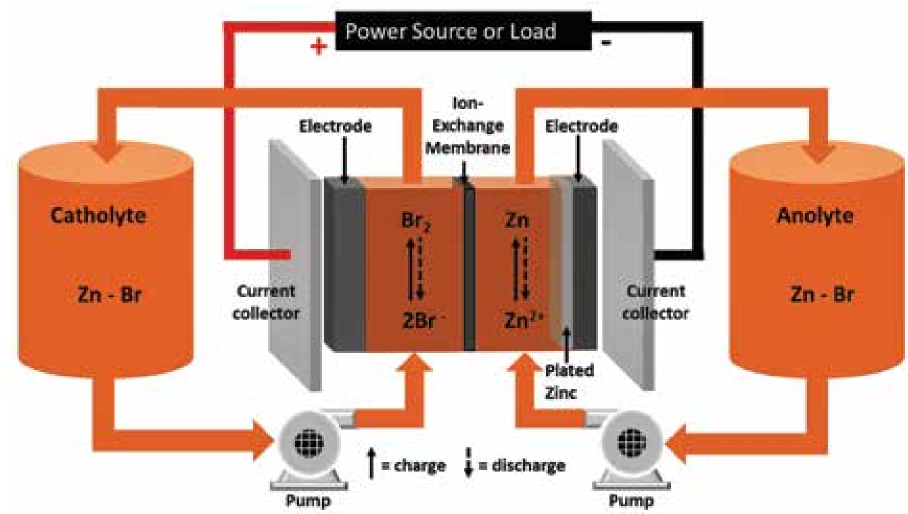


Figure 3. Schematic of zinc-bromine flow battery (ZBFB). Adapted from Reference 8.

Zinc-bromine flow battery (ZBFB or ZBB)

Development of the zinc-bromine flow battery (ZBFB) in its current form is attributed to work at Exxon in the early 1970s. Unlike most other redox flow battery types, the ZBFB is a hybrid system, in that the total energy stored is not purely proportional to the volume of electrolyte but instead depends on both the volume of electrolyte and the electrode area because zinc metal is plated onto the anode during charge. Concurrently, bromide ions are oxidized to bromine on the other side of the membrane. During discharge, the zinc metal oxidizes to Zr^{2+} and dissolves into the electrolyte, and the bromine is reduced to bromide ions.

Figure 3 shows a general schematic of ZBFBs. The figure does not depict some additional requirements related to bromine. One, bromine has limited solubility in water, so a complexing agent is needed on the cathode side to prevent its release. With bromine's high toxicity, it is essential to maintain certain conditions such as moderate system temperature to maintain the stability of the complex. Two, with bromine being highly oxidative, system components need to be specially selected, which can add to cost. There are also challenges on the anode side. Repeated plating of the zinc can cause uneven deposition and eventually dendrites of zinc can puncture the membrane. Pulsed discharge during charge may be required.

Despite these challenges, two significant benefits of a ZBFB are the high voltage and high energy density for flow batteries, associated with the two electrons per atom of zinc that are engaged in the charge-discharge process. Typical materials of construction within the cell include carbon-filled plastic (bipolar plates), carbon felt (electrodes), and membranes based on a PFSA/PTFE copolymer/polymer composite.

Conceptually, ZBFBs could be very low cost because of the raw materials, but dealing with the issues noted above frequently offsets this benefit. The potential cost reduction continues to drive work in this space (i.e., to solve or mitigate the issues and realize the benefits of the lower cost raw materials), and there are already several companies selling ZBFBs to end users. One recent development, arising from work at the University of Sydney, Australia, is the use of gel electrolytes replacing the liquid electrolytes.

All-iron flow battery (Fe-RFB)

The earliest work on the all-iron flow battery (Fe-RFB) is attributed to L. W. Hruska and R. F. Savinell in Ohio, with their first major publication on the subject in January 1981.[12] The Fe-RFB follows similar principles to those of the VRFB in that by using

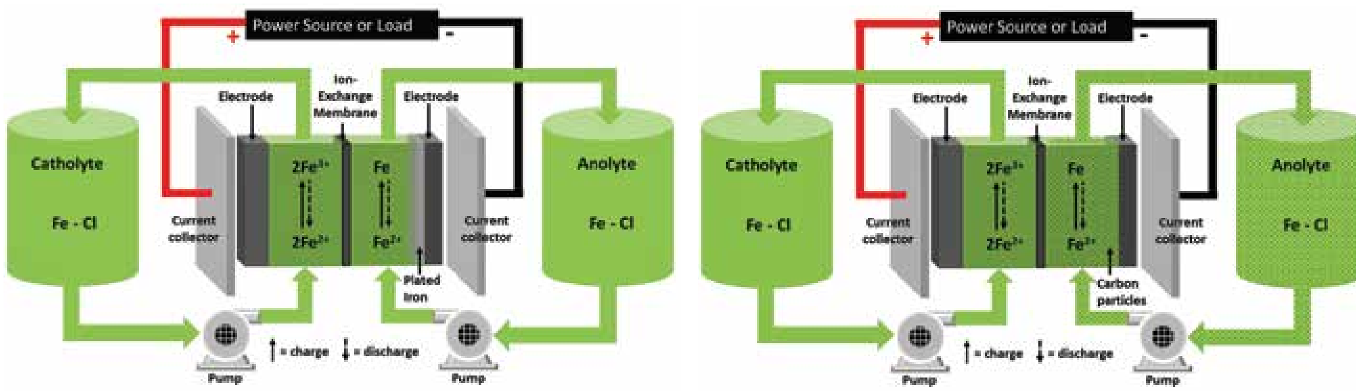


Figure 4. a) Schematic of an all-iron flow battery (Fe-RFB) (hybrid). b) Schematic of an all-iron flow battery (Fe-RFB) (slurry). Adapted from Reference 8.

the same element with multiple valence states on either side of the membrane, losses associated with cross-over contamination can be eliminated.

During charging, Fe^{2+} oxidizes to Fe^{3+} on the cathode side and Fe^{2+} reduces to iron metal on the anode side. During discharging, the reverse is true. Additionally, iron is abundant, inexpensive, and nontoxic.

While these characteristics would appear to make Fe-RFBs the ideal flow batteries, there is a major challenge caused by hydrogen generation, and frequent electrolyte rebalancing is required. Recent work at Case Western Reserve University in Cleveland, Ohio, demonstrated that a sealed Fe-RFB is possible with internal rebalancing, hence facilitating desired maintenance-free operation.[13]

As well as hydrogen evolution, other challenges include dendrite formation during iron plating and a relatively low cell voltage. Typical materials of construction within the cell include graphite (bipolar plates), carbon or graphite felt (electrodes), and microporous polyethylene (membrane).

In addition to the hybrid version of the Fe-RFB (depicted in Figure 4a), an alternative system uses a slurry at the anode side, in which the iron metal deposits on carbon particles (depicted in Figure 4b). As well as the obvious benefit of fully decoupling energy and power, this system also extends the capacity of the cell because the surface area of 3D carbon particles can be made much larger than the area of the negative electrode. This system has its own challenges, however, in that the slurry rheology must be maintained for extended periods and at different states of charge, and iron must deposit uniformly onto the particles.

There are at least three companies currently engaged in commercializing the Fe-RFB technology.

Opportunities for the ceramics community and conclusion

This period is one of rapid growth for energy storage, and redox flow batteries are likely to play an increasingly significant role. Large energy storage installations are very expensive, and already companies have experienced significant losses caused by lithium-ion battery-related fires in energy storage system (ESS) facilities in Australia, Belgium, China, England, South Korea, and the United States. The fires are difficult and dangerous to extinguish, and in at least one case resulted in loss of life.[14] While safety standards for electric vehicles are designed to allow sufficient time for occupants to leave vehicles after initiation of battery thermal events, these standards are not as relevant for ESS installations, where prevention of propagation of thermal runaway is the only acceptable solution. Lithium-ion batteries containing solid-state electrolytes will provide a solution in the future, but there are still technical and commercial hurdles to overcome before these solutions will be widely used in cost-sensitive markets.

With ESS applications, redox flow batteries offer an immediate alternative to lithium-ion batteries, and the benefit of safety far outweighs the downside of the low energy density. Solutions already exist to the main technical challenges, and if it is possible to reduce cost as well (in US$/kWh), redox flow batteries can take the leading position in this market.

Already, according to detailed estimates from the U.S. Department of Energy,[15] costs are relatively similar for longer duration systems when comparing higher energy lithium-ion battery installations versus VRFB. For example, for a 10 MW installation and 10-hour duration, total installed cost for an NMC-cathode lithium-ion battery system would be US$387/kWh and for a VRFB it would be US$426/kWh. However, the ongoing reduction of lithium-ion battery costs also needs to be considered, and it may be more difficult to reduce costs of redox flow batteries once a large scale (GWh) is reached because of the increasing relative dominance of the chemicals.

For a given redox flow battery chemistry, there are several ways in which cost can be addressed. The first and most obvious is replacement of current materials of battery construction with lower cost substitutes (lower US$, same kWh). A second way is to replace these materials with alternatives that provide improved system characteristics (same US$, higher kWh). For example, increasing the energy density of the stack will mean the total cost of the other system components will be lower on a system energy basis. A third way is to use materials that allow lower cost system design, for example, by combining components.

Bipolar plates and electrodes are usually made from carbon or graphite in a solid or flexible form. Bipolar plates by necessity must be impermeable. Electrodes can be made of flexible or rigid (porous) material, with some benefits offered by each, most notably cost for flexible materials and more uniform flow and extended life for solid ones. The membrane is highly engineered and can dominate stack component costs, particularly if it is based on a PFSA/PTFE copolymer or an equivalent polymer. Finding an alternative high-performance and lower-cost ion exchange membrane may prove to be the key to ongoing widescale commercial success for redox flow batteries, and hence presents an excellent opportunity for ceramics.

The membrane in a redox flow battery has some characteristics not significant for other battery types: it must deal with ion cross-over, i.e., selectively allowing counter-ions to pass through, but not allowing active species the same passage; it must limit water transport; it must have a low areal resistance; it must resist fouling; and it must be stable in whichever chemistry is present and at whatever pH is used to stabilize the system.

Despite their attractive properties (high proton conductivity and chemical stability), even PFSA/PTFE copolymer-based membranes are not ideal—aside from the cost, they are also selectively permeable to water and allow some cross-over of active species. One example of a ceramic which may prove suitable as a membrane in flow batteries is NaSICON, as demonstrated in recent work at Sandia National Laboratories by Eric Allcorn and others.[16] Other work identified sol-gel as a possible process route for fabrication of low-cost silica-based membranes.[17]

As we progress in this dynamic growth period for energy storage, many options are conceptually possible. However, commercialization of any new technology and scaling it to GWh level takes many years, typically decades. The two most likely systems to capture the new space are lithium-ion batteries and redox flow batteries, which have each matured sufficiently to be scalable to the required level. Although there are advantages and disadvantages of each, there is no dispute that redox flow batteries are safer from the perspective of minimizing battery-related fires.

The three chemistries of redox flow batteries which are furthest advanced are all-vanadium, zinc-bromine, and all-iron. There is yet no clear winner among these, but in each case, innovation will help to realize the potential. If a suitable membrane can be part of the fulfillment, redox flow batteries will be a major new market for the ceramics industry.

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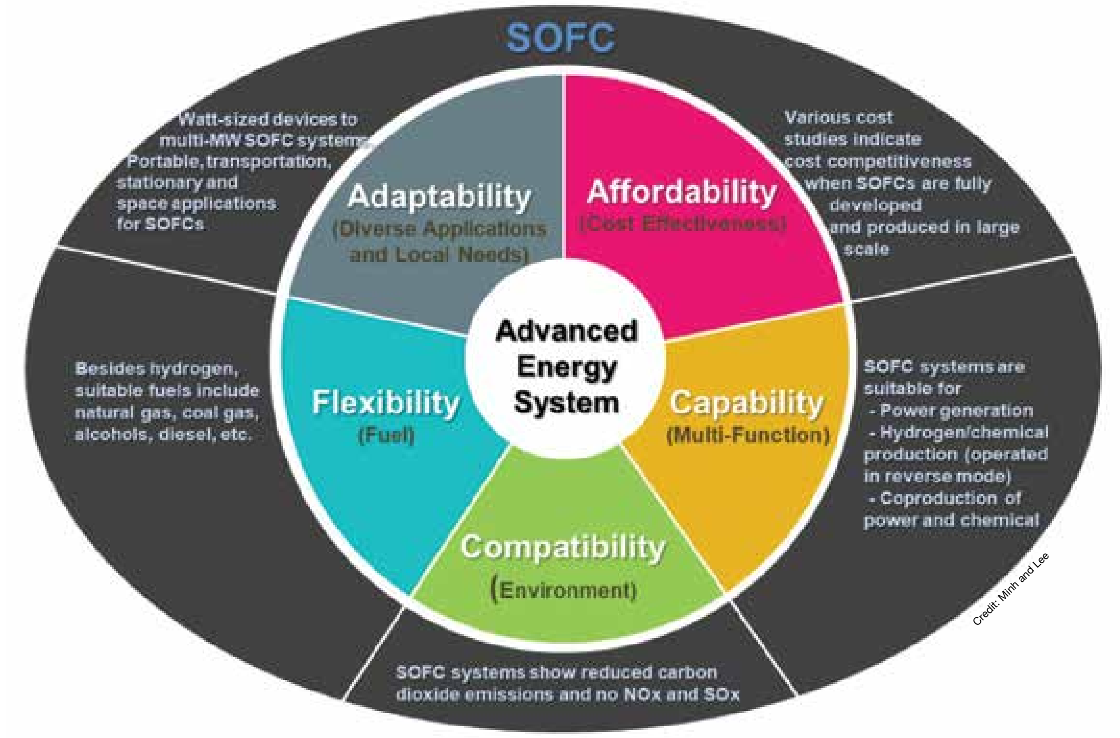


Figure 1. Characteristics of future energy systems and solid oxide fuel cell (SOFC) technology.

Solid oxide fuel cell technology for the future

By Nguyen Q. Minh and Yoon Ho Lee

Solid oxide fuel cells possess all the characteristics desired for future advanced energy systems—and recent technological advances have helped move the technology toward widespread applications.

According to the U.S. Department of Energy's Energy Information Administration (EIA), world energy consumption will increase to about 740 quadrillion Btu in 2040, rising 28% between 2015 and 2040.[1]

The EIA projects that increases in consumption will affect all energy sources—fossil (petroleum and other liquids, natural gas), renewables (solar, wind, hydro), and nuclear—except coal, which is estimated to remain flat. Although renewables are the world's fastest growing form of energy, fossil fuels are expected to continue supplying most of the energy used worldwide. As use of fossil fuels increases, it is projected that world energy-related carbon dioxide emissions will grow from about 34 billion metric tons in 2015 to about 40 billion metric tons in 2040 (an average of 0.6%/year).[1]

To meet this energy growth while limiting carbon dioxide emissions, future advanced energy systems should possess two key characteristics: flexibility (i.e., fuel flexible, suitable for efficient operation on a variety of practical fuels from fossil to renewable fuels) and compatibility (i.e., environmentally compatible, operable with reduced carbon dioxide emissions). In addition, other desirable characteristics for such a system include capability (i.e., multifunctional), adaptability (i.e., appropriate for diverse applications and versatile to local energy needs), and affordability (i.e., cost effective and cost competitive)[2] (Figure 1).

Solid oxide fuel cells (SOFCs) are one example of technology suitable to serve as a technology base for future energy systems. SOFCs are energy conversion devices that produce electricity by electrochemical combination of a fuel with air across an oxide electrolyte. The key features of an SOFC are its solid-state construction (ceramics and metals) and high operating temperature (typically 600–1,000°C). The combination of these two features leads to several advantages for SOFCs, including cell and stack design flexibility, multiple cell fabrication options, multifuel capability, and operating temperature range.

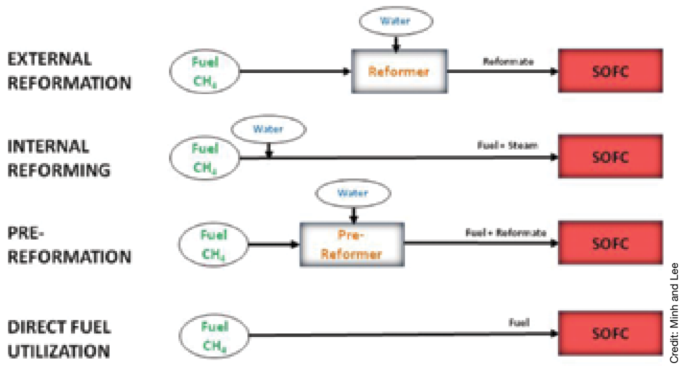


Figure 2. SOFC operating options with hydrocarbon and alcohol fuels (written for methane and steam reformer/pre-reformer).

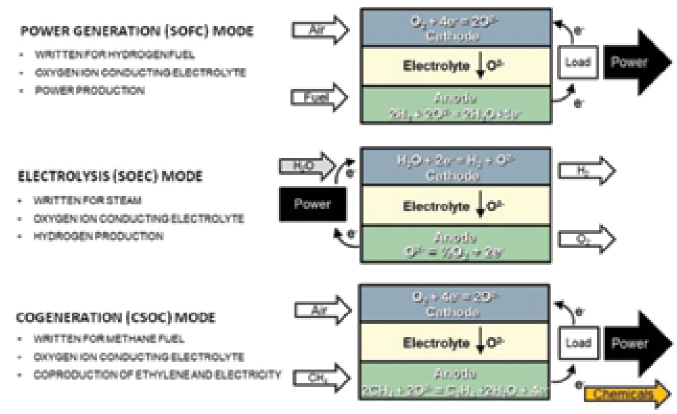


Figure 3. SOFC operation modes.

At present, the most common SOFC materials are yttria stabilized zirconia (YSZ) for the electrolyte, nickel-YSZ (Ni-YSZ) for the anode, and lanthanum strontium cobalt iron perovskite-YSZ (LSCF-YSZ) for the cathode. For multicell stacks, stainless steels are commonly used for the interconnect (to connect single cells in electrical series in a stack) and glasses for gas sealing.[3] Many other materials (e.g., oxygen ion conducting perovskites, proton conducting oxides for the electrolyte) have been considered and evaluated for SOFCs as well.

SOFCs possess all the characteristics given above for future advanced energy systems. Its fuel flexibility, adaptability, and capability in particular set the SOFC apart from many energy technologies, especially other fuel cell technologies.

Flexibility

SOFCs are fuel flexible. Like other types of fuel cells, the primary fuel for an SOFC is hydrogen. However, suitable fuels for SOFCs also include natural gas, biogas, coal gas, alcohols, and diesel. It should be noted that use of these fuels requires removal of certain contaminants, such as sulfur, and appropriate ways to prevent carbon deposition.

For fuels, especially light hydrocarbons and alcohols such as natural gas, biogas, and ethanol, an SOFC can operate with four fuel input options that incorporate different ways of fuel reforming (Figure 2). Reforming is a catalytic process that converts an input fuel, such as methane, to carbon monoxide and hydrogen. Each option has advantages and disadvantages, and selection very much depends on many factors including specific applications and requirements, designs, and operating conditions.

- *External reformation:* SOFCs can operate directly on reformates from external reformation of the fuel. No clean-up of carbon monoxide and carbon dioxide in the reformate is needed. In fact, dry CO can serve as fuel for the SOFC, and in the case of wet CO, the CO reacts to generate hydrogen fuel within the fuel cell via the water-gas shift reaction. In this mode, the SOFC operates in conjunction with an external reformer (steam reformer, autothermal reformer, or catalytic partial oxidation reformer).
- *Internal reforming:* In this operating option, fuel with significant amounts of water or carbon dioxide is fed to the SOFC and reformed on the anode of the fuel cell. This internal reforming approach can be employed to eliminate the need of an external reformer and to use the endothermic reforming reactions to reduce cooling requirements in thermal management of the SOFC. This option may require development of suitable schemes to distribute the reformation to minimize temperature gradients within the fuel cell.
- *Prereformation:* This operating option combines external reformation and stack internal reforming. In this option, only a portion of the fuel is reformed in an external reformer (in this case, referred to as a prereformer), and the resulting reformate plus the remaining fuel are fed to the SOFC, where the fuel is internally reformed (via steam reforming) within the stack. This operating option permits smaller reformers (due to partial external reformation) and improves thermal management of the fuel cell (due to internal reforming).
- *Direct fuel utilization:* The SOFC is shown to have the capability for direct fuel utilization of hydrocarbons and alcohols, meaning it can operate directly on these fuel feeds. This operating option is similar to but different from the internal reforming mode in that the fuel feed contains no water or

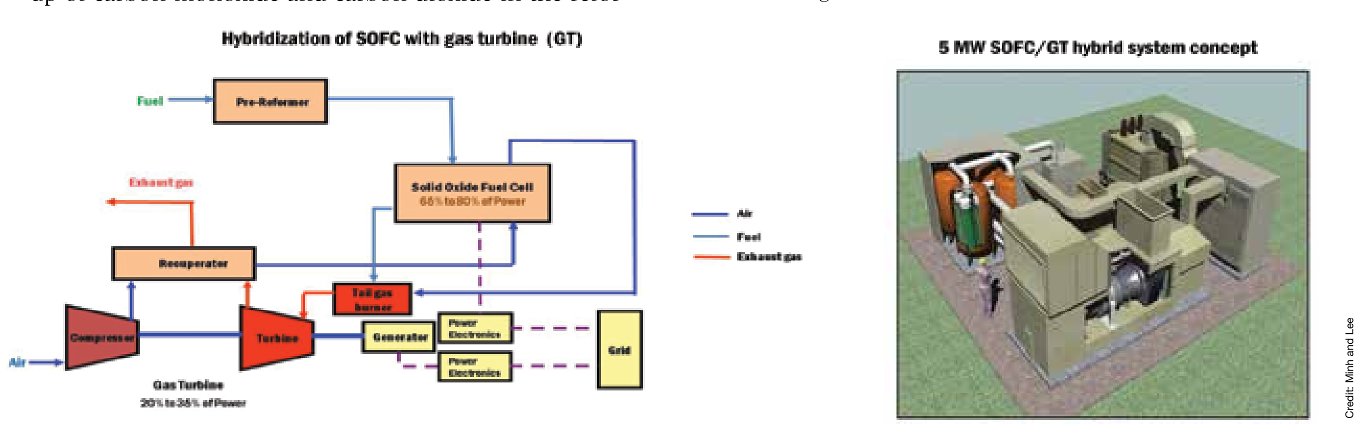


Figure 4. Hybridization of SOFC with gas turbine.

carbon dioxide. Direct utilization of hydrocarbons and alcohols in the SOFC requires modifications of the Ni-YSZ anode or use of alternative materials to prevent carbon deposition.

Capability

SOFCs are multifunctional. These devices can operate in fuel cell or SOFC mode (power generation), electrolysis or solid oxide electrolysis cell (SOEC) mode (chemical production), and cogeneration or CSOC mode (coproduction of power and chemical)[4] (Figure 3). Among these operating modes, the SOFC is the most technologically advanced. The SOEC and CSOC are based fundamentally on the SOFC, and their development to date depends on leveraging progress in SOFC technology.

SOFCs have been developed for a broad spectrum of power generation systems, ranging from watt-size devices to multimegawatt power plants that operate on a variety of fuels. The SOEC has been evaluated for hydrogen production from steam at different sizes—from distributed plants (e.g., 1,500 kg H_2/day) to central stations (e.g., 150,000 kg H_2/day), production of syngas (mixtures of H_2 and CO_2) for industrial uses, and oxygen generation/recovery from air or CO_2. The CSOC, currently at its conceptual and research stage, is considered for production of valued chemicals, e.g., ethylene from methane.

SOFC and SOEC operation modes can be combined in a unit. In other words, the unit can operate efficiently in both fuel cell and electrolysis modes, referred to as a reversible solid oxide cell (RSOC).

A special application of the SOEC is its deployment for oxygen production in space exploration. The SOEC developed for NASA's Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument was included in the rover and sent to the Martian surface to explore the planet, paving the way for future human missions. This SOEC uses solar energy to convert some of the thin, carbon dioxide-rich Mars atmosphere into oxygen, which will then be used for propellant and human breathing. The MOXIE instrument aboard on the NASA Perseverance rover demonstrated oxygen production on Mars for the first time in April 2021.[5]

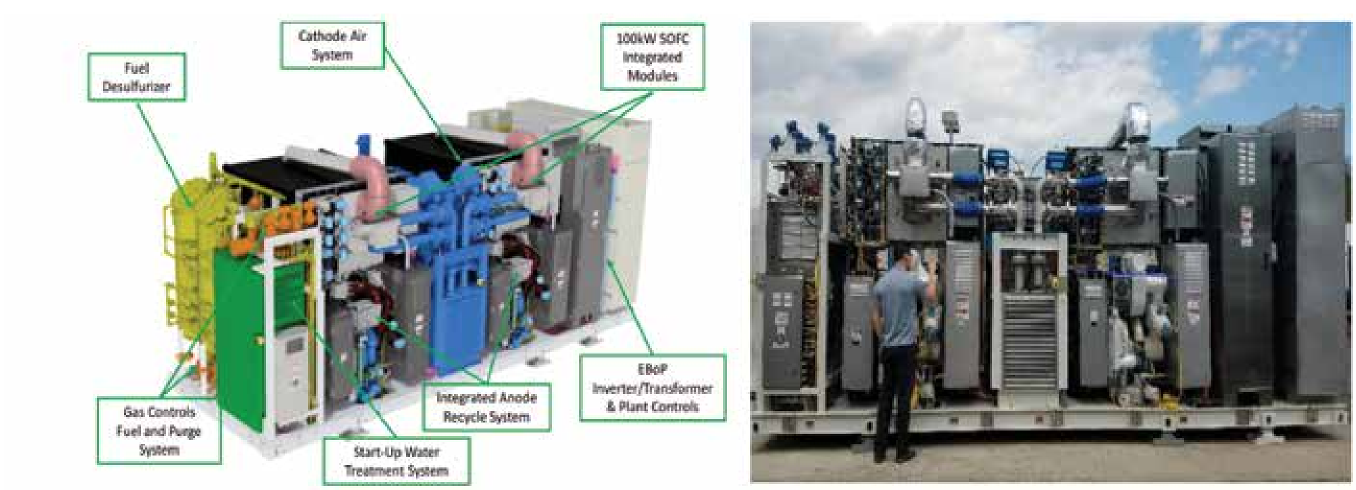
Adaptability

Examples of SOFC power systems and their applications and development/commercialization status are given in Table 1.[6]

An attractive attribute of SOFCs is the possible hybridization of the fuel cell with another power generating equipment such as a gas turbine (GT) to improve system performance.[7] In SOFC/GT hybrids, the tail gas from the SOFC is combined with ambient air and fed to the turbine section of the GT to generate additional electricity (Figure 4). An example of a 5 MW SOFC/GT system concept is also shown in Figure 4. In a generic SOFC/GT hybrid design, the SOFC produces about 65–80% of the power and about 20–35% is from the GT. Hybridization of the SOFC with

Table 1. Markets and applications of selected SOFC power systems. Adapted from Reference 6. Credit: Minh, Fuel Cell Science and Engineering

Market	Application	Power level	Readiness level
Portable	Consumer electronic devices, portable power	1–100 W	Demonstration, precommercial, commercial
	Portable power, battery chargers	200–500 W	Demonstration, precommercial, commercial
Transportation	Range extenders, automobile and truck auxiliary power units	5–50 kW	Demonstration
	Aircraft auxiliary power units, aircraft power	100 kW–30 MW	Concept
Stationary	Residential, micro combined heat and power, uninterruptible	1–10 kW	Demonstration, precommercial, commercial
	Micro combined heat and power, distributed generation	100 kW–1 MW	Demonstration, precommercial, commercial
	Baseload	100–500 MW	Concept



Credit: Ghezel-Ayagh, Proceedings

Figure 5. 200 kW SOFC demonstration system. Adapted from Reference 9.

a GT significantly improves system efficiency and can be beneficial for use in large (≥ hundreds of kilowatts) power plants. Researchers have validated operation of SOFC/GT hybrids in several demonstration systems.[7] For the SOEC, integration of SOEC systems with nuclear energy using process steam/process heat/electricity from the nuclear reactor was envisioned.[8]

Advances in design, engineering, materials, and manufacturing of SOFC technology

SOFCs are considered and developed for a wide range of applications and markets, as shown in Table 1. To date, many of the applications for SOFCs have progressed to hardware demonstration and prototype/precommercial/commercial stages with systems of power level up to 200 kW; several applications, especially those with large power outputs, are at the conceptual/design stage. Figure 5 shows an example of a 200 kW SOFC demonstration system.[9]

Significant advancements were made in the past few years in several technological areas critical to the development of SOFCs. However, further improvements are needed in several areas for cells and stacks, relating to the key drivers (efficiency, reliability, and cost) to enable commercialization. At present, SOFCs show efficiency and performance levels suitable for many applications. Reliability and durability of SOFCs demonstrated to date is adequate, although improvements in performance degradation rates, especially under practical operating conditions, are desirable.

The current critical issue facing the technology is cost. Reduction in the cost of SOFCs requires not only high-volume production but also significant changes in the materials, design, and engineering of current technology.

If the issues facing the technology are resolved, future SOFCs are expected to be an efficient, reliable, and cost-effective clean energy system that is fuel flexible and versatile in applications when fully developed. Recent innovations in design, engineering, materials, and manufacturing could help to move SOFCs toward this expectation. Selected examples of recent technology advances include development of advanced multicell stack designs, electrode microstructural engineering, application of digital manufacturing, fabrication of thin-film SOFCs, incorporation of nanomaterials and nanostructures, and direct utilization of hydrocarbons and other fuels. The following discussion and examples are based mainly on the on-going efforts at the University of California, San Diego on design, research, and concept development for SOFC technology.

Advanced multicell stack design

One recent development in SOFC stack technology is the design concept based on a prime surface interconnect configuration. The key feature of this configuration is a one-piece metallic interconnect that incorporates both fuel and oxidant flow fields, with peaks on one side of the interconnect serving as flow channels (valleys) on the other side.[10]

Figure 6 shows an example schematic stack concept, including the prime-surface interconnect configuration with an egg carton shaped flow field. This stack concept has several attractive features, including reduced weight and volume, flexibility

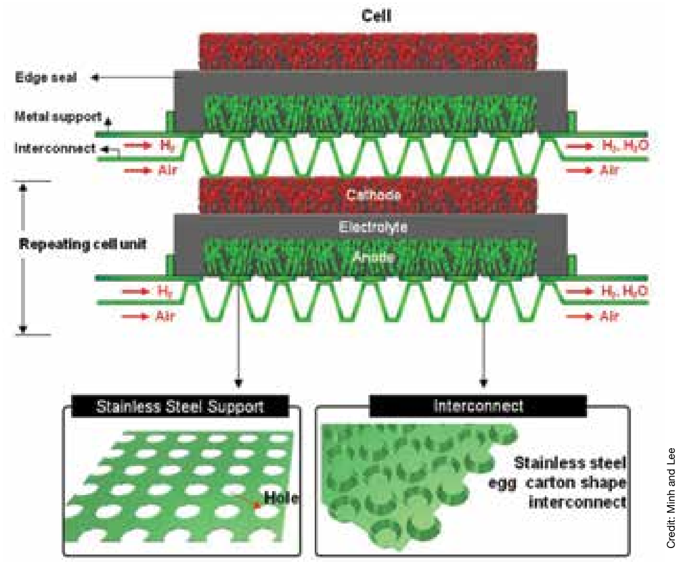


Figure 6. Stack design concept incorporating egg carton shaped prime surface interconnect.

in gas flow configuration, minimal stacking performance losses, and improved sealing. These features lead to lower cost, better performance, and enhanced reliability for the stack. Another important attribute of this stack concept is its versatility in incorporating different types of cell construction (e.g., conventional sintered cells, such as sintered anode-supported cells, and metal-supported cells). The metal-supported cell configuration permits thin cell components, facilitates cell scale-up, and can be designed for reduced temperature operation, all of which reduce cost and increase reliability and durability.

Electrode microstructure engineering

An example in this area is engineering the anode microstructure to prevent the anode's redox instability (chemomechanical instability of the anode under oxygen partial pressure changes during redox cycles at high temperatures).

Current SOFC cells based on YSZ electrolytes use almost exclusively Ni-YSZ compositions for the anode. The Ni-YSZ anode can become unstable because of the oxidation of the nickel (i.e., redox instability) if fuel supply is interrupted, the cell is operated under extremely high fuel utilization/high current conditions, or seal leakage occurs. Oxidation of the nickel increases the volume of the anode, and the volume expansion creates stresses in the layers (compression in the anode and tension in the electrolyte), which can cause cracks in the electrolyte, especially the thin electrolyte in the case of anode-supported cells.

At UCSD, researchers proposed an engineered structure concept to enhance robustness, reliability, and endurance of

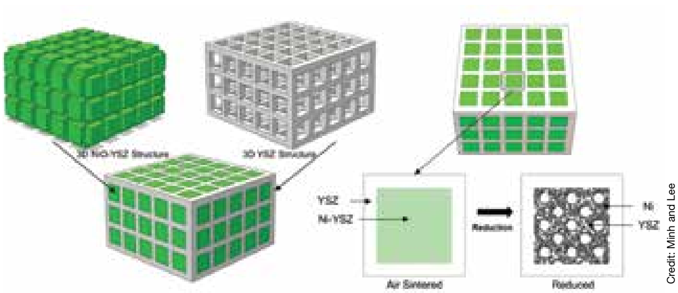


Figure 7. Proposed engineered Ni-YSZ anode microstructure concept

SOFC Ni-YSZ anodes. SOFC anodes of this engineered microstructure consist of specifically designed 3D networks of nickel and YSZ, with each phase topologically connected throughout the anode. Figure 7 schematically shows an example of such an engineered microstructure (with nickel(II) oxide in oxidation state and nickel in reduction state). The controlled connectivity and the engineered microstructure, especially of the YSZ, in contrast to the random connection and microstructure in conventional nickel-based anodes, strengthen the anode structure and prevent dimensional changes during anode reduction and oxidation, thus significantly increasing robustness and enhancing reliability and endurance of the anode.

Digital manufacturing

Additive manufacturing shows promise for fabrication of complex SOFC structures, such as the proposed engineered anode structure discussed above.

An additive manufacturing process constructs parts with intricate shapes from 3D model data, usually layer by layer. As opposed to subtractive manufacturing (e.g., machining) and formative manufacturing (e.g., casting), the additive manufacturing process does not penalize complexity of design with additional equipment or labor costs.

The anode structure can be fabricated by a variety of additive manufacturing techniques, including 3D microextrusion, aerosol jet, or inkjet printing.

Thin-film technology

Thin-film SOFCs were recently developed for miniaturization of the fuel cell (for applications requiring small size and light weight) and for efficient operation at lower temperatures (400–600°C). Operating the SOFC at lower temperatures while maintaining adequate cell performance provides several benefits, such as decreased deleterious chemical interactions and reduced thermal stresses, and thus increased cell reliability.

Researchers have used different deposition processes to fabricate components for thin-film SOFCs. Among various physical vapor deposition processes, sputtering is a versatile technique commonly used in mass production as it can create either porous or dense films just by changing the deposition conditions.

Figure 8 presents typical micrographs of SOFC components and a thin-film cell made by sputtering on anodized aluminum oxide (AAO) substrate. This cell has a gadolinium doped ceria, or GDC, interlayer between the electrolyte and cathode to minimize interactions between LSCF and YSZ. As seen from the figure, the sputtered components have the desired density/porosity characteristics: fully dense electrolyte, fully dense interlayer, porous anode, and porous cathode layer. Examination and characterization of single cells indicate uniform layer thickness, well-defined interfaces, and excellent adherence between layers.

Nanomaterials and nanostructures

In recent years, a major development in SOFC R&D work is the demonstration of using nanomaterials to modify electrode microstructure, thus electroactivity, as a potent means for performance enhancement. As the operating temperature of the fuel cell is reduced, it is more feasible to incorporate nanomaterials and nanostructures in SOFCs due to their improved long-term stability.

Nanomaterials and nanostructures can be introduced into the cell by adding the material to existing porous electrode structures (for example, by infiltration of a precursor solution followed by decomposition), by forming from elements present in existing structures (for example, by exsolution), or by depositing using different deposition techniques.

Figure 9 shows an example of the cathode and anode nanostructures made by sputter deposition. The electrodes in this case are made of a columnar nanostructure with a diameter of about tens of nanometers with nanofiber-like branches growing onto the columnar structure. This type of nanostructure significantly enlarges electrode active areas, resulting in exceptionally high-power densities for the cell that can be as high as 3W/cm^2 at 650°C depending on cell configurations and electrode materials.[12] As an example, a sputtered cell incorporating such electrodes exhibits excellent performance at reduced temperatures of 550–650°C (versus 800–1,000°C for conventional SOFCs) as shown in Figure 10.

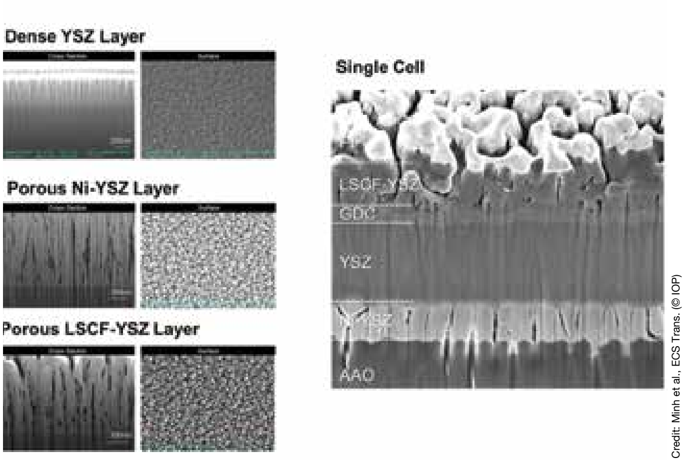


Figure 8. Micrographs of sputtered SOFC components and single cell. Adapted from Reference 11.

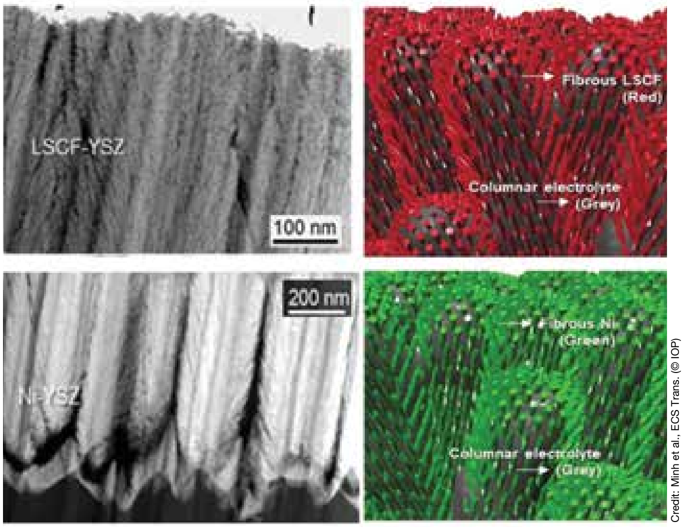


Figure 9. Sputtered electrode nanostructure. Adapted from Reference 11.

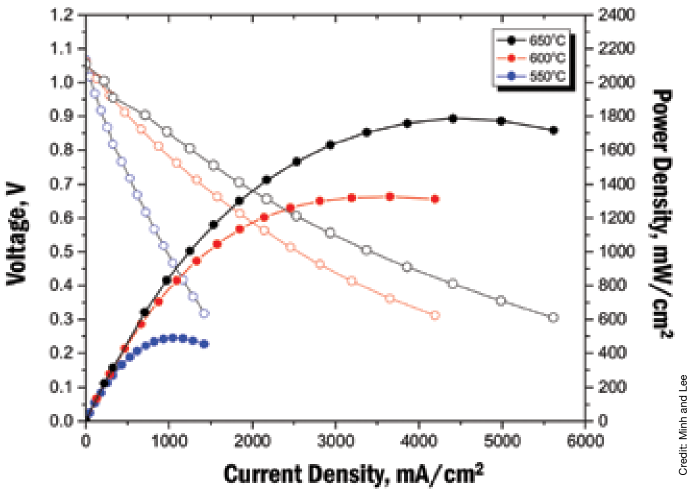


Figure 10. Performance of cell LSCF-YSZ/GDC/YSZ/Ni-YSZ featuring sputtered nanoscale electrodes.

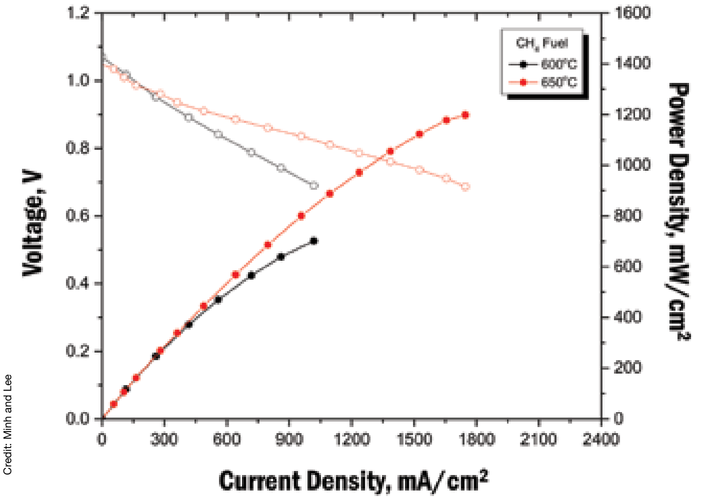


Figure 11. Performance of sputtered thin-film SOFC on dry methane.

Direct fuel utilization

One example in this area is the recent demonstration at UCSD of direct operation of the SOFC with excellent performance using dry methane. As discussed earlier, for fuels other than hydrogen, SOFCs can operate directly on the fuel (Figure 2). Direct fuel utilization is the preferred approach to operating SOFCs with fuels like hydrocarbons and alcohols because it removes the need for an external reformer in such a power system. This absence of an external reformer reduces cooling requirements due to less heat generated by direct oxidation of the fuel, and it can lead to higher system efficiency and lower system cost if adequate performance is maintained for the fuel cell. (In other words, if performance of the fuel cell with direct fuel utilization matches the performance level of fuel cells using externally reformed fuel.)

Researchers have demonstrated the feasibility of direct-fueled SOFCs. Figure 11 shows an example of direct methane utilization in a sputtered thin-film SOFC cell tested at UCSD. The cell performance indicates a superior power density of about 1,200 mW/cm^2 at the temperature of 650°C. The issues of carbon deposition and long-term durability of course need to be addressed in this case.

Concluding remarks

SOFCs have the potential to serve as a base technology for future energy systems, as it has all the desirable attributes of compatibility (environment), flexibility (fuel), capability (multiple function), adaptability (diverse application), and affordability (cost effectiveness). SOFC technology has made significant progress toward commercialization, with several applications (buildings/facilities, residential CHPs, portable power) at precommercial or commercial stages. Recent technological advances have helped to improve the performance, reliability, and cost of the technology. However, significant challenges, especially in the area of cost, must be addressed and resolved to move the SOFC toward widespread applications in the future.

Acknowledgments

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Credit: DOE AMO

Figure 1. Overview of DOE's programs and resources that support manufacturers in improving energy performance and reducing GHG emissions.

How DOE's no-cost technical assistance resources support today's glass and ceramics manufacturers

Contributed by the U.S. Department of Energy's Advanced Manufacturing Office

The U.S. Department of Energy (DOE) recognizes that an efficient and robust domestic manufacturing sector is essential for creating high-paying American jobs and ensuring a prosperous economy.

To that end, DOE's Advanced Manufacturing Office (AMO) is committed to fostering a strong, diverse base of American manufacturers that lead the world in sustainability and innovation.

To support U.S. industry, AMO invests in research, development, demonstration, and deployment for technologies that catalyze innovation, improve energy performance, lower emissions, and reduce the cost of new materials and processes in manufacturing. Glass and ceramics are critical to this mission, from providing materials relied on by a wide range of industries to supporting U.S. technological leadership in manufacturing the components required for a clean energy economy, including solar cells, fuel cells, and thermoelectric generators.

No-cost programs and resources available to manufacturers

AMO offers a range of technical assistance and workforce development resources that can support glass and ceramics manufacturers today. Together, they aim to provide manufacturers with advanced technical support and expertise, energy management assistance, and access to open-source tools and software to identify and implement energy- and emissions-saving opportunities (Figure 1).

Better Plants Program

AMO's Better Plants Program is a voluntary initiative that encourages U.S. manufacturing companies to set aggressive energy efficiency and sustainability goals. In return, partners receive advanced technical assistance and trainings, opportunities for networking and peer-to-peer knowledge sharing, and national recognition for their achievements.

As of fall 2021, Better Plants' more than 250 partners had cumulatively saved over $9.3 billion in energy costs since 2009 at over 3,500 nationwide facilities, representing 13.8% of the U.S. manufacturing energy footprint.[1] When joining Better Plants, partners commit to reducing their portfolio-wide energy intensity by approximately 25% over 10 years. Partners also have the option to join at the Challenge level, which involves making an additional commitment to share energy efficiency and decarbonization strategies, data, and solutions with other industrial companies to facilitate economy-wide emissions reductions. DOE works closely with partners to support them in achieving their goals.

To learn more about Better Plants and/or become a partner, visit https://betterbuildingssolutioncenter.energy.gov/better-plants/join or email BetterPlants@ee.doe.gov.

Advanced technical assistance

Better Plants partners are provided with robust technical assistance through a dedicated technical account manager (TAM). TAMs work closely with partners to develop energy management plans and goals, which includes establishing energy baselines, developing energy management plans, identifying energy-saving and energy-recovery opportunities, and tracking energy performance metrics.

TAMs are also subject-matter experts in a range of relevant technology focus areas, including building envelope and modeling, combined heat and power, heat waste management, compressed air, fans, lighting, motors, process cooling and HVAC, process heating, pumps, refrigeration, steam, water, renewables, microgrids, diagnostic equipment, energy-systems software, smart manufacturing, techno-economic analysis, life cycle assessment analysis, economic feasibility analyses, and carbon reduction targets.

Visit https://betterbuildingssolutioncenter.energy.gov/better-plants/technology-focus-areas to learn more about TAMs.

In-plant trainings

Better Plants offers expert-led multiday workshops that train participants to identify, implement, and replicate energy efficiency projects. In response to the COVID-19 pandemic, the Better Plants team pivoted to offer virtual in-plant trainings that focus on a range of energy-saving topics, including energy management (50001 Ready), steam systems, fan systems, pumping systems, process heating, ammonia refrigeration, water efficiency, and wastewater treatments. Together, these virtual workshops have trained over 600 employees of partner companies, helping to identify over $2 million in energy efficiency opportunities.

Industry networking

Better Plants regularly offers a variety of opportunities for partners to engage with one another and other industry experts. These opportunities include the Better Buildings, Better Plants Summit; industrial sector meetups; and interactive workshops and discussion sessions.

Learn more about the Better Buildings, Better Plants Summit at https://betterbuildingssolutioncenter.energy.gov/summit.

Peer-to-peer knowledge sharing and recognition

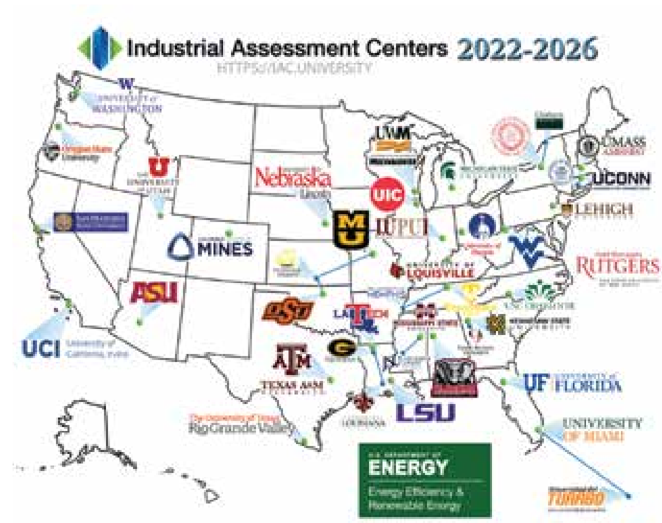
Better Plants features partner achievements in DOE materials and publications and at events and site visits. Case studies illustrating how partners met their goals are broadcasted on the Better Plants Solution Center, which is viewed by thousands of organizations and media outlets each year. The Better Plants team highlights successful strategies from goal achievers through resource documents and guides to best practices. Annual awards highlight innovative accomplishments in energy management and project implementation.

To explore the Better Plants Solution Center, visit https://betterbuildingssolutioncenter.energy.gov/better-plants/solutions.

Better Climate Challenge

Better Plants is also actively recruiting for the Better Climate Challenge, where organizations partner with DOE to reduce portfolio-wide greenhouse gas emissions by at least 50% within 10 years, with energy-intensive industries (as defined by the U.S. Energy Information Administration) committing to a 25% in reduction. In return, DOE provides technical assistance, opportunities for peer-to-peer exchange and knowledge sharing, and national recognition for achievements.

To learn more about the Better Climate Challenge and/or become a partner, visit https://betterbuildingssolutioncenter.energy.gov/better-climate-challenge.



Credit: DOE AMO

Figure 2. Map of DOE's Industrial Assessment Centers.

Industrial Assessment Centers

DOE's 32 Industrial Assessment Centers are an excellent resource for small- and medium-size manufacturers that are looking to improve their energy use, reduce costs, and/or take the first step toward reducing emissions.

IACs are comprised of university-based engineering students and faculty that perform no-cost energy assessments and make energy-saving recommendations at industrial facilities (Figure 2).

IAC energy assessments include a remote survey of the plant, followed by a 1–2 day site visit where the IAC team takes engineering measurements. Following the site evaluation, the team prepares a confidential report for the plant that details the analysis, findings, and recommendations. Several months after the recommendations are made, the IAC team checks in with the plant to determine which recommendations were implemented.

To date, IACs have conducted over 19,500 assessments, making more than 148,000 recommendations with average annual savings of $137,594.[2] All IAC assessments, recommendations, and implemented rates are tracked in a publicly available IAC Database (https://iac.university/#database), which also serves as an informative resource for companies seeking ideas for energy-saving opportunities.

IACs train the next generation of the energy engineering and energy management workforce, with over 60% of IAC student participants pursuing careers in the energy field following graduation. IACs also conduct research, offer training webinars focused on various energy management topics, and publish papers and case studies highlighting notable recommendations and implementation strategies.

To learn more about IACs and apply for an assessment, visit https://iac.university.

Energy management assistance

DOE understands the critical role that energy performance management can play in saving energy, reducing costs, and increasing competitiveness.[3] To that end, DOE's 50001 Ready and Superior Energy Performance 50001 (SEP 50001) programs support and recognize facilities and organizations that attest to implementing energy management systems aligned with the International Organization for Standardization (ISO) 50001. ISO 50001 is the global standard for energy management systems, providing organizations with a framework and specific requirements for system implementation.

50001 Ready

The 50001 Ready program offers a no-cost, audit-free alternative recognition program for organizations that implement an energy management system in accordance with the principles of the ISO 50001 standard. A central tool for the program is the 50001 Ready Navigator, which is a "Turbo Tax-like tool" that provides partners with step-by-step guidance to carry out the 25 tasks required to implement an ISO 50001-based energy management system.

To date, DOE has recognized 77 organizations for completion of the 50001 Ready program. The program now also includes virtual cohorts that receive 6–12 months of ISO 50001 expert support in the form of training webinars, virtual coaching sessions, and tailored guidance.

Learn more about the 50001 Ready at https://betterbuildingssolutioncenter.energy.gov/iso-50001/50001Ready. Check out the 50001 Ready Navigator at https://navigator.lbl.gov.

Superior Energy Performance 50001

The Superior Energy Performance 50001 program provides elevated levels of recognition (at the Silver, Gold, or Platinum level) to facilities that implement the ISO 50001 standard and demonstrate improved energy performance. Achievements are verified by an independent third party.

Learn more about the Superior Energy Performance 50001 program at https://betterbuildingssolutioncenter.energy.gov/iso-50001/sep-50001.

DOE is actively recruiting for its 50001 Ready Cohorts program, which provides tailored technical assistance to groups of energy team members of U.S.-based industrial, commercial, or institutional sites as they implement as ISO 50001-based energy management system. To learn more and apply, email 50001Ready@lbl.gov.

Combined heat and power deployment

DOE offers a comprehensive deployment support for combined heat and power (CHP), which is an efficient technology that generates on-site electric power and thermal energy from a single fuel source, achieving overall efficiencies of up to 75%.[4]

A central pillar of the CHP deployment program is the CHP Technical Assistance Partnerships (TAPs), 10 regional centers that provide unbiased, fact-based engineering support and technical assistance to industrial and commercial facilities that could benefit from deploying CHP, microgrids, and/or district energy technologies. CHP TAPs help identify opportunities for plants, support project planning, and conduct economic payback analyses.

The CHP deployment program also offers various no-cost resources, including a comprehensive CHP Project Profiles Database and a CHP eCatalog that facilitates side-by-side comparisons of packaged CHP systems.

For more information and assistance, contact the CHP TAP in your area: https://betterbuildingssolutioncenter.energy.gov/chp/chp-taps.

No-cost software and tools

AMO provides support for a range of no-cost software and tools that are designed to help manufacturers and water treatment plants improve energy efficiency and advance decarbonization efforts.

MEASUR Software Suite

Manufacturing Energy Assessment Software for Utility Reduction (MEASUR) is a suite of open-source software tools that allow partners to model facility data, evaluate energy use, and improve energy efficiency of industrial systems.

Learn more at https://www.energy.gov/eere/amo/measur.

REopt Lite Tool

The Renewable Energy Integration & Optimization (REopt) Lite web-based tool allows users to conduct feasibility and resiliency analyses for solar, wind, combined heat and power, and battery storage potential.

Learn more at https://reopt.nrel.gov/tool.

Financing Navigator

DOE's Financing Navigator allows companies to evaluate a broad range of financing options for energy efficiency and renewable energy projects. The tool also facilitates user connections with the Financial Ally community, which is comprised of banks and lenders that are actively seeking energy efficiency and renewable energy projects to finance.

Learn more at https://betterbuildingssolutioncenter.energy.gov/financing-navigator.

Low carbon tools and calculators

DOE also has developed low carbon tools and calculators, including a Low Carbon Action Plan Tool that helps partners develop pathways for decarbonization of selected plants, a Carbon Inventory Calculator that helps companies track carbon emissions, and the Electrification Impact Calculator that can be used to evaluate the cost and emissions reduction associated with replacing fuel-based equipment with electrical equipment.

To learn more about AMO's no-cost software tools, visit https://betterbuildingssolutioncenter.energy.gov/better-plants/software-tools. Open-source software can be downloaded at the AMO Github page: https://ornl-amo.github.io. If you are interested in a demonstration or training, contact us at BetterPlants@ee.doe.gov.

Use cases

AMO welcomes additional ceramics and glass manufacturers to partner with us and leverage DOE tools and resources. The successes of ACerS members illustrated below demonstrate the benefits of these partnerships (Figure 3).

Saint-Gobain

Saint-Gobain, an ACerS Diamond Corporate Partner and Better Plants Partner, is a multinational corporation that designs, manufactures, and distributes materials and solutions for buildings, transportation, infrastructure, and industrial applications.

Saint-Gobain has set ambitious energy efficiency and emissions reduction goals for their industrial sites, including a 20% reduction in energy intensity by 2026, a 33% reduction in Scope 1&2 emissions by 2030, and net-zero greenhouse gas emissions by 2050.

As a Better Plants partner, DOE supports Saint-Gobain's sustainability goals by providing technical expertise and recognition while sharing best practices. Saint-Gobain was recently awarded the Better Plants' 2021 Better Practice Award for the development of their "Green Awards" program, which recognizes employee researchers for R&D projects focused on various sustainability issues, including emissions reductions, energy savings, waste reduction, reduction of raw materials, and improvements in worker safety. Saint-Gobain was also awarded the 2017 Better Practice Award for their company's Water, Waste, and Energy (WWE) Program, which inspired competition among Saint-Gobain's 130+ manufacturing sites to improve sustainability practices while highlighting solutions and recognizing top-performing locations.

Saint-Gobain takes advantage of a range of resources available to Better Plants partners. For example, the Field Validation and Diagnostic Equipment Program provided a loaned flow meter and expert technical support from DOE's National Laboratories that uncovered as much as $20,000 in potential energy savings. Saint-Gobain is currently participating in Better Plants' Low Carbon Pilot, which aims to showcase real-world pathways of how industrial facilities have achieved substantial emissions reductions. Additionally, Saint-Gobain employees regularly attend the Better Buildings, Better Plants Summit; virtual in-plant trainings; and Better Plants' Technology Days, which allows partners to tour DOE's National Labs.

3M

ACerS Corporate Partner, Better Plants Partner, and Better Climate Challenge Participant 3M is a multinational Fortune 100 manufacturer that produces a broad range of products including abrasives, tapes, personal protective equipment, filtration material, films, medical devices, and many more.

As a Better Plants Goal Achiever, 3M successfully met its initial goal to achieve a 25% reduction in energy intensity of 111 facilities by 2016. 3M is now focusing on a new set of ambitious goals, including a 25% reduction in energy intensity from a 2015 baseline by 2025, a 50% reduction in Scope 1&2 emissions by 2030, and carbon neutrality by 2050.

To help meet its sustainability goals, 3M has adopted an enterprise-wide approach to implement an ISO 50001-based energy management system, with 30 facilities certified to ISO 50001 and 13 also holding DOE's Superior Energy Performance (SEP) certification. In just 3 years, 3M's 30 certified sites improved their energy performance by 4.5%, collectively decreasing emissions by 330,000 CO_2-equivalent tons and decreasing energy costs by $13.5 million. AMO's Technical Partnerships team supported this effort by organizing expert-led in-house trainings on DOE's 50001 Ready Program and the 50001 Ready Navigator tool.

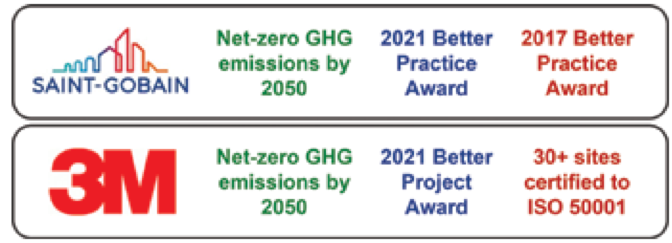


Figure 3. Sustainability goals, recognition, and achievements of ACerS Corporate and Better Plants Partners Saint-Gobain and 3M.

3M was recently awarded the Better Plants' 2021 Better Project Award for implementing a battery-less, real-time, cloud-based stream trap monitoring system that substantially reduced the amount of natural gas and water required to generate steam, saving $32,000 annually in energy costs. In addition, 3M is currently participating in the Better Plants' Low Carbon Pilot and regularly attends DOE's virtual in-plant trainings.

Looking forward

AMO is committed to supporting a clean and competitive U.S. manufacturing enterprise into the future and is actively advancing initiatives in the following areas:

Validation of innovative technology

DOE is providing verification, validation, and deployment support for emerging technologies with significant energy and carbon-saving potential. Interested technology vendors and/or industrial sites are encouraged to apply for the Industrial Technology Validation pilot at https://betterbuildingssolutioncenter.energy.gov/better-plants/industrial-technology-validation-pilot.

Education and workforce development

AMO is ramping up efforts to strengthen the manufacturing workforce by providing diverse resources to students and professionals. Explore DOE's workforce development resources by visiting: https://betterbuildingssolutioncenter.energy.gov/workforce.

Focus on energy-intensive industries

AMO is increasingly focused on developing resources and providing technical assistance that supports energy efficiency improvements and emissions reductions in energy-intensive industries.

AMO welcomes feedback on challenges and opportunities in ceramics and glass manufacturing. A forthcoming webinar with ACerS will cover current technical assistance opportunities and future engagement.

If you are interested in connecting with us, please reach out to Christina Walrond at christina.walrond@ee.doe.gov.

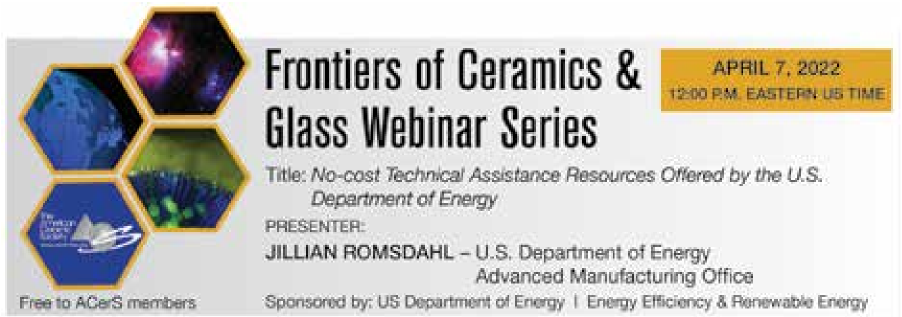
References

[1]U.S. Department of Energy, "Better Plants 2021 Progress Update" (2021). https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/2021_Better_Plants_Progress_Update.pdf

[2]Advanced Manufacturing Office Industrial Assessment Center Newsletter Winter 2021 (2021). https://www.energy.gov/sites/default/files/2021-07/IAC%20Winter%202021%20Newsletter_7.6.2021_FINAL.pdf

[3]U.S. Department of Energy, Energy Efficiency & Renewable Energy, "ISO 50001 boosts U.S. productivity, economy, competitiveness" (2017). https://betterbuildingssolutioncenter.energy.gov/iso-50001/business-case

[4]U.S. Department of Energy and U.S. Environmental Protection Agency, "Combined heat and power: A clean energy solution" (2012). https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/chp_clean_energy_solution_0.pdf ■



Meet Jillian Romsdahl

Jillian Romsdahl is an AAAS Science & Technology Policy Fellow supporting the Advanced Manufacturing Office within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. Within AMO, she supports the Technical Partnerships team, which manages a range of programs that offer resources and technical assistance to improve energy efficiency and reduce emissions in manufacturing.

ACerS 123rd Annual Meeting at MS&T21 highlights ACerS' commitment to diversity

Attendees gathered for an informal networking reception during ACerS Annual Meeting sponsored by GE Global Research and hosted by the ACerS Diversity & Inclusion Subcommittee.

For the first time in two years, people were able to gather once more in-person for ACerS Annual Meeting at MS&T.

The American Ceramic Society, The Minerals, Metals & Materials Society (TMS), and the Association for Iron & Steel Technology (AIST) held MS&T virtually in 2020 due to the COVID-19 pandemic. This year, the three societies welcomed everyone to downtown Columbus, Ohio, on Oct. 17–20, 2021.

More than 1,000 people registered to attend in-person, plus just under an additional 500 registrants signed up for the virtual On-Demand option. Students impressively accounted for about 40% of the registrations.

"We were very pleased to be able to convene over 1,000 people in person in Columbus, Ohio. Although we definitely missed many of our international members who were unable to attend due to travel restrictions, we found it extremely rewarding to be able to reconnect with our community. We are looking forward to future meetings when we can convene our global community," says Mark Mecklenborg, ACerS executive director.

Below are highlights from ACerS Annual Meeting at MS&T21.

Diversity and inclusion shine at ACerS Annual Meeting

Diversity and inclusion were topics that came up consistently throughout the four-day conference.

During ACerS Annual Business Meeting on Monday, Oct. 18, outgoing ACerS president Dana Goski overviewed the details of ACerS' new strategic plan, which will guide the Society in the coming years. One of the main goals is to expand ACerS' global culture of inclusion and actively working to develop membership within underrepresented groups. One way the Society plans to achieve this goal is by adding a new Diversity, Equity, and Inclusion position to each of its committees.

The Society's commitment to diversity and inclusion is also evident through two events that took place during the Annual Meeting. On Sunday, Oct. 17, attendees gathered for the MS&T Women in Materials Science Reception sponsored by Elsevier. On Tuesday, Oct. 19, attendees gathered for an informal networking reception sponsored by GE Global Research and hosted by the ACerS Diversity & Inclusion Subcommittee to encourage engagement with the new ACerS Diversity & Inclusion Member Community.

Award lectures push the boundaries of next-generation technology

The Society and Division award lecturers at ACerS Annual Meeting shined a light on several next-generation technologies that are poised to revolutionize the ceramic and glass industry.

The Navrotsky award lecture on Monday, Oct. 18 by Xin Qian of the Georgia Institute of Technology discussed the development of solar-driven fuel production as an alternative to reliance on fossil fuels. Qian's talk was followed later in the day by the Friedberg Ceramic Engineering lecture by University of Virginia professor Beth Opila, who overviewed the increasing use of environmental barrier coatings in aerospace applications.

On Tuesday, Oct. 19, Penn State Materials Research Institute director Clive Randall presented the Edward Orton, Jr. Memorial Lecture during the morning plenary session, providing an overview of the nascent processing technique of cold sintering. The final award lecture—the Sosman Award—took place Wednesday, Oct. 20, and Technion – Israel Institute of Technology professor Wayne D. Kaplan presented on combining atomistic and continuum approaches to understanding ceramic interfaces.

The winner of this year's Rustum Roy Award, Fraunhofer IKTS president and TU Dresden professor Alexander Michaelis, and Cooper Distinguished Speaker Award, National Hellenic Research Foundation Theoretical and Physical Chemistry Institute director of research Efstratios I. Kamitsos, unfortunately were unable to attend in-person. Fortunately, meeting organizers arranged for a recording of their lectures—on advanced ceramics for energy and environmental technology, and structure and ion dynamics in glass, respectively—to be played instead.

ACerS Annual Meeting at MS&T22 will take place Oct. 9–13, 2022, in Pittsburgh, Pa. Additionally, the MS&T exhibition will be co-located with the Advanced Materials Show and the Nanotechnology Show. "We believe that this development will strengthen our exhibit presence while we continue to provide a great technical program," Mecklenborg says.

Visit the ACerS Flickr page at https://bit.ly/MST21photos for more photos from ACerS Annual Meeting at MS&T21. ■

REGISTER TODAY! JAN. 19–21, 2022

ELECTRONIC MATERIALS AND APPLICATIONS 2022

DoubleTree by Hilton | Orlando, Fla., USA | ceramics.org/ema2022 | Hybrid Conference

ORGANIZED BY THE ACerS ELECTRONICS AND BASIC SCIENCE DIVISIONS

ACerS is pleased to announce the addition of a hybrid option for EMA '22 to allow participation by individuals who cannot attend in-person due to travel restrictions. We plan to provide a hybrid solution that will incorporate prerecorded talks from virtual attendees into the live onsite programming. All live sessions will be recorded for all attendees to view at the conclusion of the live conference, available until March 31, 2022.

Electronic Materials and Applications 2022 (EMA 2022) is an international conference focused on electroceramic materials and their applications in electronic, electrochemical, electromechanical, magnetic, dielectric, biological, and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society, EMA 2022 will take place at the DoubleTree by Hilton Orlando at Sea World, Jan. 19–21, 2022.

EMA 2022 is designed for scientists, engineers, technologists, and students interested in basic science, engineering, and applications of electroceramic materials. Participants from across the world in academia, industry, and national laboratories exchange information and ideas on the latest developments in theory, experimental investigation, and applications of electroceramic materials.

Students are highly encouraged to participate in the meeting. Prizes will be awarded for the best oral and poster student presentations.

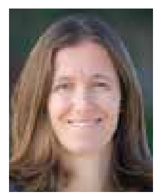
The technical program includes plenary talks, invited lectures, contributed papers, poster presentations, and open discussions. EMA 2022 features symposia focused on dielectric, piezoelectric, pyroelectric, magnetoelectronic, (multi)ferroic, quantum, relaxor, optoelectronic, and photonic ceramics; complex oxide thin films, heterostructures, and nanocomposites; semiconductors; superconductors; ion-conducting ceramics; 5G materials for millimeter-wave technology; and functional biological materials. Other symposia emphasize broader themes covering processing, microstructure evolution, and integration; effects of surfaces and interfaces on processing, transport, and properties; point defects, dislocations, and grain boundaries; mesoscale phenomena; and advanced characterization and computational design of electronic materials.

EMA includes several networking opportunities to facilitate collaborations for scientific and technical advances related to materials, components, devices, and systems. The Basic Science Division will again host a tutorial session in addition to the regular conference programming.

The grand finale of the meeting will again be Failure: The Greatest Teacher. We invite anyone interested to submit a brief abstract for this educational and engaging event that concludes the meeting.

Please join us in Orlando, Fla., to participate in this unique experience!

ORGANIZING COMMITTEE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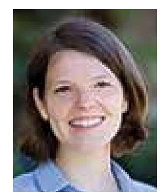
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Dillon

Shen Dillon, (Basic Science Division)
University of California, Irvine, USA
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TECHNICAL PROGRAM

- **S1 – Characterization of Structure–Property Relationships in Functional Ceramics**
- **S2 – Advanced Electronic Materials: Processing Structures, Properties, and Applications**
- **S3 – Frontiers in Ferroic Oxides: Synthesis, Structure, Properties, and Applications**
- **S4 – Complex Oxide Thin Films and Heterostructures: From Synthesis to Strain/Interface-engineered Emergent Properties**
- **S5 – Mesoscale Phenomena in Ferroic Nanostructures: From Patterns to Functionalities**
- **S6 – Emerging Semiconductor Materials and Interfaces**
- **S7 – Superconducting and Related Materials: From Basic Science to Applications**
- **S8 – Structure–Property Relationships in Relaxor Ceramics**
- **S9 – Ion-conducting Ceramics**
- **S10 – Point Defects and Transport in Ceramics**
- **S11 – Evolution of Structure and Chemistry of Grain Boundaries and Their Networks as a Function of Material Processing**
- **S12 – 5G Materials and Applications Telecommunications**
- **S13 – Agile Design of Electronic Materials: Aligned Computational and Experimental Approaches and Materials Informatics**
- **S14 – Functional Materials for Biological Applications**
- **S15 – Advanced Microelectrics**

REGISTER TODAY! JAN. 23–28, 2022

46TH INTERNATIONAL CONFERENCE AND EXPOSITION ON ADVANCED CERAMICS AND COMPOSITES

Hilton Daytona Beach Resort and Ocean Center | Daytona Beach, Fla., USA | Hybrid Conference | ceramics.org/icacc2022

ORGANIZED BY THE ENGINEERING CERAMICS DIVISION OF THE AMERICAN CERAMIC SOCIETY

We are pleased to announce that the 46th International Conference & Exposition on Advanced Ceramics & Composites (ICACC 2022) will be held from Jan. 23–28, 2022, in Daytona Beach, Fla. This conference has a strong history of being the preeminent international meeting on advanced structural and functional ceramics, composites, and other emerging ceramic materials and technologies. The Engineering Ceramics Division (ECD) of The American Ceramic Society has organized this esteemed event since 1977. Due to the high quality of technical presentations and unique networking opportunities, this event has achieved tremendous worldwide interest and has attracted active participation from ceramic researchers and developers from the global technical community thanks to the dedication and support of our membership.

We look forward to seeing you in Daytona Beach, Fla., in January 2022. Check out our hybrid option if you are unable to travel.

Palani Balaya, program chair, ICACC 2022
National University of Singapore | mpepb@nus.edu.sg

PLENARY SPEAKERS

Monday, Jan. 24

THOMAS SPECK, University of Freiburg and Cluster of Excellence Living, Adaptive and Energy-autonomous Materials Systems (livMatS), Germany

Plant materials systems and structures: Bio-inspiration for a "greener" technology in the 21st century

Y. SHIRLEY MENG, Zable Chair Professor in Energy Technologies and professor in Materials Science & NanoEngineering, University of California San Diego, USA

Designing better ceramic materials for future batteries

GLOBAL YOUNG INVESTIGATOR AWARD

Sunmi Shin, National University of Singapore, Singapore

Thermal engineering using infrared photonic structures: Probing coherent thermal emission in a single nano-object

MECHANICAL PROPERTIES OF CERAMICS AND GLASS 2022 SHORT COURSE

Jan. 27–28, 2022 | 8:30 a.m. – 5 p.m.

Location: In conjunction with ICACC2022, Hilton Daytona Beach Resort and Ocean Center, Daytona Beach, Fla., USA

Instructor: **George D. Quinn, NIST**

SYMPOSIA

- S1: **Mechanical Behavior and Performance of Ceramics and Composites**
- S2: **Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications**
- S3: **19th International Symposium on Solid Oxide Cells (SOC): Materials Science and Technology**
- S4: **Armor Ceramics – Challenges and New Developments**
- S5: **Next Generation Bioceramics and Biocomposites**
- S6: **Advanced Materials and Technologies for Rechargeable Energy Storage**
- S7: **16th International Symposium on Functional Nanomaterials and Thin Films for Sustainable Energy Harvesting, Environmental and Health Applications**
- S8: **16th International Symposium on Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials and Systems (APMT16)**
- S9: **Porous Ceramics: Novel Developments and Applications**
- S10: **Modeling and Design of Ceramics and Composites**
- S11: **Advanced Materials and Innovative Processing Ideas for Production Root Technologies**
- S12: **On the Design of Nanolaminated Ternary Transition Metal Carbides/Nitrides (MAX Phases) and Borides (MAB Phases), Solid Solutions thereof, and 2D Counterparts (MXenes, MBenes)**
- S13: **Development and Applications of Advanced Ceramics and Composites for Nuclear Fission and Fusion Energy Systems**
- S14: **Crystalline Materials for Electrical, Optical, and Medical Applications**
- S15: **6th International Symposium on Additive Manufacturing and 3D Printing Technologies**
- S16: **Geopolymers, Inorganic Polymers, and Sustainable Materials**
- S17: **Advanced Ceramic Materials and Processing for Photonics and Energy**
- S18: **Ultrahigh-temperature Ceramics**

REGISTER TODAY! March 15–18, 2022

The Unified International Technical Conference on Refractories (UNITECR) is a biennial international conference that contributes to the progress and exchange of industrial knowledge and technologies concerning refractories.

SYMPOSIA TITLES

- Advances in Installation Techniques, Manufacturing, and Equipment
- Advances in Monolithic Technology
- Iron and Steelmaking Refractories
- Modeling and Simulation of Refractories
- New Developments in Refractory Formulation
- Nonoxide Refractory Systems
- Raw Materials
- Refractories for Aluminum
- Refractories for Cement and Lime
- Refractories for Glass
- Refractories for Other Applications
- Refractories for Petrochemical Applications
- Refractory Education
- Refractory Characterization and Testing
- Refractory Technology and Techniques for Energy Savings
- Safety, Environmental Issues, and Recycling
- Use of Artificial Intelligence, Machine Learning, and Big Data in Refractory Technology
- Refractory Student and Young Professionals Symposium
- Theodore J. Planje Award Symposium

TENTATIVE SCHEDULE OF EVENTS

Tuesday, March 15, 2022	
Welcome event	6–10 p.m
Wednesday, March 16, 2022	
Opening ceremony	8:30–9:30 a.m.
Exhibits	9:30 a.m. – 7 p.m.
Technical sessions	9:30 a.m. – 5:30 p.m.
Exhibit reception and posters	5–7 p.m.
Thursday, March 17, 2022	
Exhibits	9:30 a.m. – 4:30 p.m.
Technical sessions	8 a.m. – 5 p.m.
Banquet	7–10 p.m.
Friday, March 18, 2022	
Technical sessions	8 a.m. – 12:30 p.m.
Lunch/Panel discussions/Closing	12:30–5:30 p.m.

EXHIBITS AND SPONSORSHIPS

Companies who want to network and do business with refractory related manufacturers, users, technologists, and scientists should contact us today for premium exhibit space and special sponsorship opportunities. For more information, contact:

Andrea Ross | 614-794-5820 | aross@ceramics.org

International Journal of Ceramic Engineering & Science

Peer-reviewed proceedings articles will be published in ACerS' open-access *International Journal of Ceramic Engineering & Science*. All articles will be posted online for conference attendees. Go to www.UNITECR2022.org for full meeting details, including publishing options.

2022 GLASS & OPTICAL MATERIALS DIVISION ANNUAL MEETING

MAY 22–26, 2022

CALL FOR PAPERS

JAN. 7, 2022

https://ceramics.org/gomd2022

HYATT REGENCY BALTIMORE | BALTIMORE, MD., USA

*Join the **Glass & Optical Materials Division (GOMD)** for its annual meeting May 22–26, 2022, in Baltimore, Md. The 2022 GOMD meeting is special because the United Nations declared 2022 the "International Year of Glass." We will have a number of special events to commemorate this occasion as we meet together in-person for the first time since 2019.*

This year's program will feature four symposia: Fundamentals of the Glassy State; Glass and Interaction with its Environment—Fundamentals and Applications; Optical and Electronic Materials and Devices—Fundamentals and Applications; and Glass Technology and Cross-cutting Topics.

Technical leaders from industry, national laboratories, and academia will lead technical sessions featuring oral and poster presentations that provide an open forum for glass scientists and engineers worldwide to present and exchange findings on recent advances in various aspects related to glass science and technology.

Students are encouraged to enter their presentations in the annual poster competition for professional recognition and cash awards. Students attending the 2022 GOMD meeting are invited to attend a career roundtable discussion with scientists from industry, national laboratories, and academia about career opportunities and other topics in a casual environment. This 2022 GOMD meeting will provide a unique opportunity for students to learn, interact, and win.

Nestled in the heart of downtown, the Hyatt Regency Baltimore Inner Harbor hotel offers a luxury gateway to the enchanting waterfront town. The conference venue is only 12 miles from Baltimore/Washington International Thurgood Marshall Airport (BWI) and within walking distance to museums, historic landmarks, restaurants, and attractions like the National Aquarium and Camden Yards.

On behalf of the GOMD executive committee and volunteer organizers, we sincerely hope you will join us at the 2022 GOMD meeting to find new collaborative opportunities and to exchange ideas in the international glass community.

2022 PROGRAM CHAIRS

Ashutosh Goel
Rutgers University
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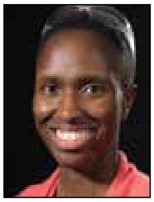

Charmayne Lonergan
Pacific Northwest National Laboratory
charmayne.lonergan@pnnl.gov

SPECIAL SESSION

Remembering Ted Day

This session is dedicated to the memory of our friend and colleague, Ted Day, who passed away in Sept. 2020. Speakers will review Ted's many contributions to our glass and bioceramics communities, as an entrepreneur, a philanthropist, and a dedicated member of The American Ceramic Society. If you would like to contribute to this session, share a memory, or offer a story, please contact Richard Brow (brow@mst.edu) or Julian Jones (julian.r.jones@imperial.ac.uk).

TECHNICAL PROGRAM

S1: FUNDAMENTALS OF THE GLASSY STATE
- Glass Formation and Structural Relaxation
- Glass Crystallization and Glass-ceramics
- Structural Characterizations of Glasses
- Topology and Rigidity
- Atomistic Simulation and Predictive Modeling of Glasses
- Data-based Modeling and Machine Learning for Glass Science
- Mechanical Properties of Glasses
- Non-Oxide Glasses and Glass-ceramics
- Glass Under Extreme Conditions

S2: GLASS AND INTERACTIONS WITH ITS ENVIRONMENT — FUNDAMENTALS AND APPLICATIONS
- Glasses and Glass-ceramics for Healthcare
- Nuclear Waste Immobilization
- Dissolution and Interfacial Reactions
- Surfaces and Coatings

S3: OPTICAL AND ELECTRONIC MATERIALS AND DEVICES — FUNDAMENTALS AND APPLICATIONS
- Laser Interactions with Glasses
- Charge and Energy Transport in Disordered Materials
- Optical Fibers and Waveguides
- Glass-based Optical Devices and Detector Applications
- Optical and Photonic Glass and Glass-ceramics

S4: GLASS TECHNOLOGY AND CROSS-CUTTING TOPICS
- Sol-gel Processing of Glasses and Ceramic Materials
- Challenges in Glass Manufacturing
- 3D-printing of Glass

Calendar of events

January 2022

19–21 Electronic Materials and Applications 2022 (EMA 2022) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; https://ceramics.org/ema2022 – HYBRID EVENT

23–28 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC2022) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; https://ceramics.org/icacc2022 – HYBRID EVENT

March 2022

9–10 Sustainable Industrial Manufacturing (SIM) – Brussels, Belgium; https://sustainableindustrialmanufacturing.com/europe

15–18 17th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; https://ceramics.org/unitecr2021

May 2022

9–12 ACerS 2022 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Charlotte Hotel, Charlotte, N.C.; https://ceramics.org/scpd2022

22–26 Glass & Optical Materials Division Annual Meeting (GOMD 2022) – Hyatt Regency Baltimore, Baltimore, Md.; https://ceramics.org/gomd2022

June 2022

13–15 12th Advances in Cement-Based Materials (Cements 2022) – University of California, Irvine; https://ceramics.org/cements2022

21–22 ceramitec 2022 – Munich, Germany; https://www.ceramitec.com/en/trade-fair/information/exhibition-sectors

28–30 2022 FIRE-ECerS Summer School: Eco-Design of Refractories – RWTH Aachen University, Germany; https://ecers.org/news/146/419/0622-FIRE-ECerS-SUMMER-SCHOOL/d,ceramic_details_conferences

July 2022

3–8 ➨ ICG Annual Meeting 2022 – Berlin, Germany; https://ceramics.org/event/icg-annual-meeting-2022

10–14 International Congress on Ceramics (ICC9) – Krakow, Poland; https://ceramics.org/event/international-congress-on-ceramics-icc9

24–28 Pan American Ceramics Congress and Ferroelectrics Meeting of Americas (PACC-FMAs 2022) – Hilton Panama, Panama City, Panama; https://ceramics.org/PACCFMAs

August 2022

29–31 ➨ 7th Ceramics Expo co-located with Thermal Technologies Expo – Huntington Convention Center, Cleveland, Ohio; https://ceramics.org/event/7th-ceramics-expo

September 2022

7–9 5th Energy Harvesting Society Meeting – Falls Church Marriott Fairview Park, Falls Church, Va.; https://ceramics.org/event/5th-energy-harvesting-society-meeting

October 2022

14–19 ACerS 124th Annual Meeting with Materials Science & Technology 2022 – David L. Lawrence Convention Center, Pittsburgh, Pa.; https://ceramics.org/event/acers-124th-annual-meeting-with-materials-science-technology-2022

August 2023

NEW DATE

27–31 The International Conference on Sintering 2023 (Sintering 2023) – Nagaragawa Convention Center, Gifu, Japan; https://www.sintering2021.org

July 2024

14–19 International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; www.ceramics.org

Dates in **RED** denote new event in this issue.

Entries in **BLUE** denote ACerS events.

➨ denotes meetings that ACerS cosponsors, endorses, or otherwise cooperates in organizing.

denotes International Year of Glass event

denotes virtual meeting

Career Opportunities

Business Services

custom finishing/machining

classified advertising

custom/toll processing services

firing/melting/drying

laboratory/testing services

liquidations/used equipment

maintenance/repair services

ADINDEX

JANUARY-FEBRUARY 2022

‡Find us in *ceramicSOURCE* 2021 Buyer's Guide

AMERICAN CERAMIC SOCIETY bulletin

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Rishabh Kundu
Guest columnist

From the Perseverance Mars Rover to car seat climate control: The plurality of thermoelectrics in application

Thermoelectric devices are small, light, and reliable solid-state energy converters that do not produce vibration or noise owing to the absence of mechanical moving parts.[1] Many ceramics—including certain metal oxides, titanium sulfides, and manganese silicides—are promising thermoelectric materials.[2]

When thermoelectric devices are exposed to a temperature gradient, an electromotive force (voltage) develops, which leads to power generation—the Seebeck effect.[2] Conversely, when an electric current is passed through thermoelectric materials, depending on the direction of the flow of current, heat is absorbed or evolved—the Peltier effect.[1] The aforementioned phenomena in thermoelectrics make them a sustainable candidate for green electricity generation and cooling or heating purposes in many applications.

For example, the Perseverance Mars Rover, like most deep-space probes, stays alive and functional through electricity generated by a radioisotope power system. In Perseverance's power system, called the "Multi-Mission Radioisotope Thermoelectric Generator," the radioactive decay of plutonium generates heat that is converted to electricity by lead telluride-based thermoelectrics.[3] Thermoelectric or Seebeck generators are also used in power plants to convert waste heat into electricity.

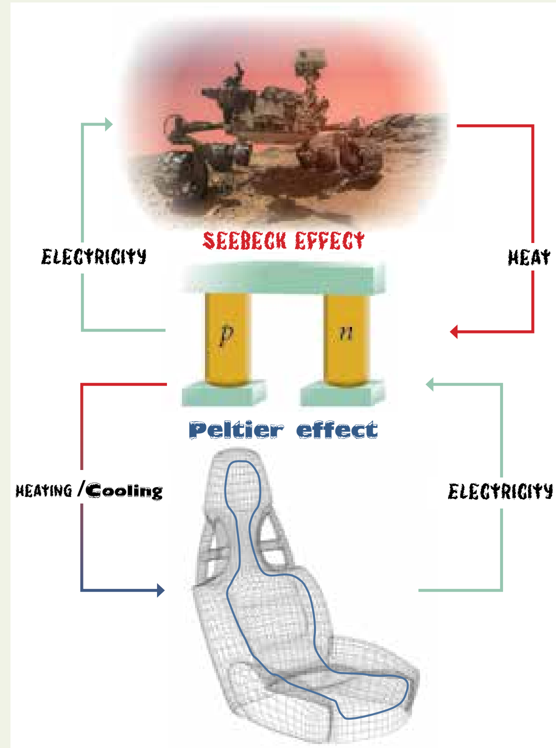
Researchers have explored using small-scale thermoelectric generators in wireless sensor networks as well, to create "self-powered devices" by replacing or reducing conventional charging. Human health monitoring, portable electronic devices, wearable devices, and devices within the Internet of Things are example applications of such thermoelectric-driven networks.[4]

The automotive industry is another application area of thermoelectric devices. Temperature is a crucial parameter in determining the comfort level of a car's internal environment,[5] but the primary air conditioning system generally used to regulate internal temperature is a fuel-intensive process. If targeted seat temperature control systems are employed, fuel consumption can be reduced by up to 0.5%, leading to fewer greenhouse gas emissions.[6]

Thermoelectric coolers using the Peltier effect can provide targeted cooling as required in cars seats. Plus, the temperature setting can be easily switched by reversing the direction of applied current—allowing the devices to cool seats in the summer and warm them during the winter. Moreover, as the thermoelectric coolers are solid-state devices, they will not make any noise, thereby adding to comfort.

Thermoelectric coolers also are used for microprocessor cooling, in dehumidifiers, and certain portable coolers. Moreover, thermoelectric cooling does not release environmentally nonbenign chlorofluorocarbons.

I bear a tenacious affection toward materials for environment and energy applications because I find immense potential in their development to build a safer, cleaner, and sustainable environment for the future generations. My current work involves trying to enhance the yield of desired phases in Half-Heusler thermoelectric materials, which will improve the material's efficiency.



Credit: Rishabh Kundu (concept) and ACerS (final design)

Figure 1. Schematic representation of the diversity of applications of thermoelectrics.

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Rishabh Kundu is a young materials science researcher from India. He is currently pursuing his MSc. in materials science from Technische Universität Darmstadt, Germany, and is associated with the Materials & Resources Research Group there as a student research assistant, working on thermoelectrics. Outside of school and lab work, he runs a blog to expose young minds to the vast world of materials science: https://ceramicsandglass.wordpress.com.

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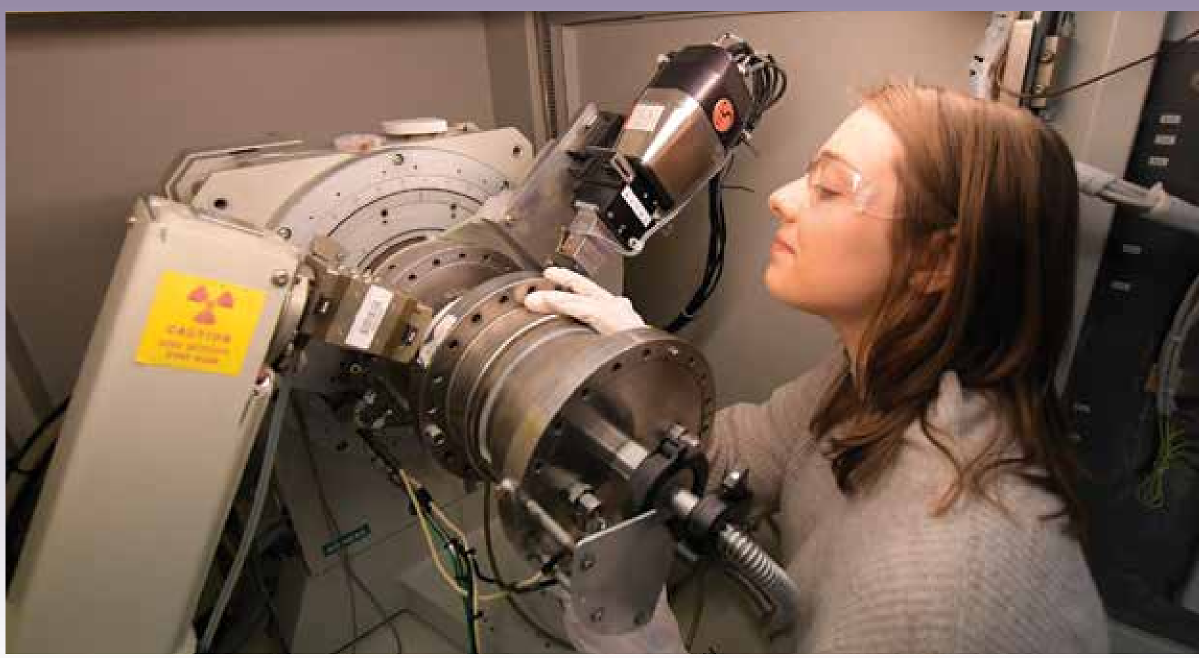

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