AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

AUGUST 2023

Lithium: The 21st century 'gold' rush

Chile and the clean energy transition | USGS Mineral Commodity Summaries 2023

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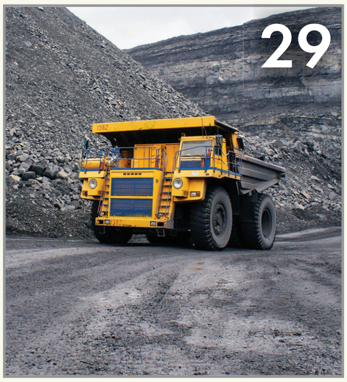

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Correction

In the June/July 2023 issue of the *ACerS Bulletin*, student member Brittney Hauke's name was misspelled within Spotlight. This error has been corrected in the archival version of the issue.

Cover image

Salar de Atacama, the largest salt flat in Chile and the third largest in the world. *Credit: Francesco Mocellin, Wikimedia (CC BY-SA 3.0)*

online
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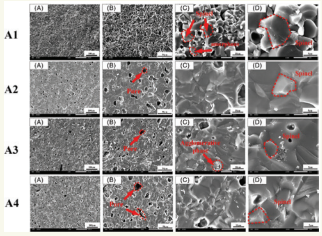
http://bit.ly/acerstwitter http://bit.ly/acerslink http://bit.ly/acersfb

As seen on *Ceramic Tech Today*...



Credit: Wu et al., *International Journal of Applied Ceramic Technology*

Effect of magnesium source on a ceramic's final properties

Starting materials can often be derived from different sources, but the impact that material source has on a product's properties is generally less studied than other factors, such as synthesis technique. Researchers from Wuhan University of Technology explored the effect of different magnesium sources on the production of magnesium aluminate spinel.

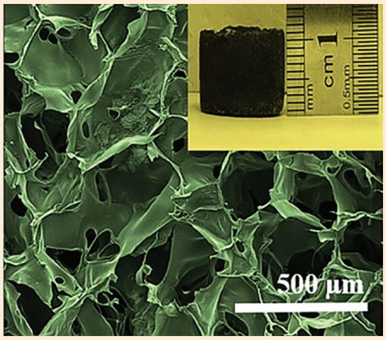
Read more at www.ceramics.org/magnesium-source

Also see our ACerS journals...

Overview and perspectives of solid electrolytes for sodium batteries
By S. Vasudevan, S. Dwivedi, and P. Balaya
International Journal of Applied Ceramic Technology

Fe_2O_3 powder modified with $Ce_{0.6}Mn_{0.3}Fe_{0.1}O_2$ and Cr_2O_3 prepared by spray pyrolysis method for rechargeable Fe–air cell
By T. Ishihara, H. Kim, Y. Inoishi, and J. Matsuda
Journal of the American Ceramic Society

Development of al-doped $MgMn_2O_4$-based cathode materials for magnesium ion cells
By R. Rosli, O. Othman, N. H. Harudin, et al.
International Journal of Applied Ceramic Technology



Recycled ZnO-fused macroporous 3D graphene oxide aerogel composites for high-performance asymmetric supercapacitors
By K. Hassan, R. Hossain, and V. Sahajwalla
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

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. 102, No. 6, pp. 1–40. All feature articles are covered in Current Contents.

news & trends

UK announces new plan, new partnership for semiconductor industry

With the drive toward electrification and data-centric processes in nearly every industry, demand for semiconductor chips grows louder by the day.

In the past year, the United States, the European Union, and India all released multibillion-dollar plans for bolstering domestic chip supply chains. The United Kingdom was expected to release a semiconductor strategy soon as well, but political instability led to a series of delays.

In May 2023, the United Kingdom finally announced its strategy, as well as a new Japanese partnership, for supporting the semiconductor industry.

The Hiroshima Accord

On May 18, U.K. prime minister Rishi Sunak met with Japan prime minister Fumio Kishida to sign a new strategic partnership deal ahead of the G7 Summit. Dubbed the "Hiroshima Accord," the deal aims to boost cooperation between the nations in a broad range of areas, including defense, clean energy, cybersecurity, and semiconductors.

Regarding semiconductors specifically, the countries will use the partnership "to explore ambitious joint research and development collaboration across semiconductor technologies, capitalizing on our respective strengths including in chip design, advanced packaging, compound semiconductors, and advanced materials," as stated in the accord.

£1 billion semiconductor strategy 'too little,' according to industry

On May 19, the United Kingdom released its semiconductor strategy.

The National Semiconductor Strategy states that the U.K. government will invest up to £200 million (US$249 million) into the country's semiconductor sector over the years 2023–25 and up to £1 billion (US$1.24 billion) in the next decade.

Instead of focusing on the construction of massive fabrication plants, the U.K. designed its strategy to focus on parts of the semiconductor industry that the country has expertise in, such as intellectual property and design of non-silicon chips.

So far, the strategy has received a cool reception from the U.K. semiconductor industry, with companies saying it will be too little to make a difference. As U.K. Shadow Secretary of State for Digital, Culture, Media, and Sport Lucy Powell points out in an article on *The Guardian*, "Rather than the £1bn headline, the reality is £200m over the next three years—significantly less ambition than our competitors."

However, some companies say the plan is a good start because it "rightly focuses on the areas where the U.K. is a global leader," as stated by Americo Lemos, chief executive of the compound semiconductor wafer manufacturer IQE, in a *Financial Times* article.

The National Semiconductor Strategy is available at https://bit.ly/UKChipStrategy. ■

Cement Association of Canada takes concrete steps toward a net-zero cement and concrete industry

The Cement Association of Canada (CAC), which describes itself as "the voice of Canada's cement industry," represents five vertically integrated cement companies across Canada that are committed to helping Canadians build thriving, sustainable, and resilient communities.

In the past year, CAC's advocacy work gained new prominence with the release of Canada's 2030 Emissions Reduction Plan in March 2022 (https://bit.ly/2030EmissionsReductionPlan). The 2030 Emissions Reduction Plan is the first of several emissions reduction plans to be issued under the Canadian Net-Zero Emissions Accountability Act.

This act, which became law in June 2021, codifies the government of Canada's commitment to achieve net-zero greenhouse gas emissions by 2050. It requires that regular emissions reduction plans be developed to ensure that Canada achieves each of its five-year national emissions reduction targets. The first plan released in March describes the ongoing and planned actions that will help Canada reach its emissions reduction target of 40–45% below 2005 levels by 2030.

Upon the plan's release, CAC announced that it looked forward to working with the federal government to achieve the plan's goals. In August 2022, it confirmed this commitment by being the first to join Canada's Net-Zero Challenge, which encourages businesses to develop and implement plans to transition their facilities and operations to net-zero emissions by 2050.

In November 2022, CAC and the government of Canada announced the release of the Roadmap to Net-Zero Carbon Concrete by 2050 (https://bit.ly/RoadmapNetZeroConcrete2050). The roadmap, which CAC helped develop, provides guidance on the technologies, tools, and policies needed for the Canadian cement industry to achieve net-zero carbon emissions while remaining competitive in a global net-zero economy. It includes the near-term Action Plan to 2030, which addresses immediate efforts and lays out a plan for research and development projects to achieve the 2050 targets.

In May 2023, CAC released yet another document to support the success of these emission reduction plans. The Concrete Zero action plan (https://bit.ly/ConcreteZero), announced May 2, outlines five priority areas the cement and concrete industry will focus on to reach net zero. These areas are

- Eliminating use of coal and petroleum coke as fuel sources for clinker production while increasing the use of lower-carbon and alternative fuels.
- Reducing volume of clinker used to produce cement, which will achieve a 1.5 Mt CO_2 emissions reduction over the course of the decade.
- Increasing the use of supplementary cementitious materials, such as fly ash. Ground limestone, recycled concrete fines, calcined clays, and other new promising materials will also play an important role.
- Working toward building carbon capture, utilization, and storage capacity. Part of that effort will be to build by 2030 North America's first commercial deployment of a full-scale carbon capture and storage project at a cement plant.
- Advocating for performance-based codes, standards and specifications, procurement policies, and increased material efficiency in construction. ■

Australia announces National Electric Vehicle Strategy

In mid-April 2023, the Australian government released its National Electric Vehicle Strategy.

The strategy sets out three key objectives to support EV adoption:

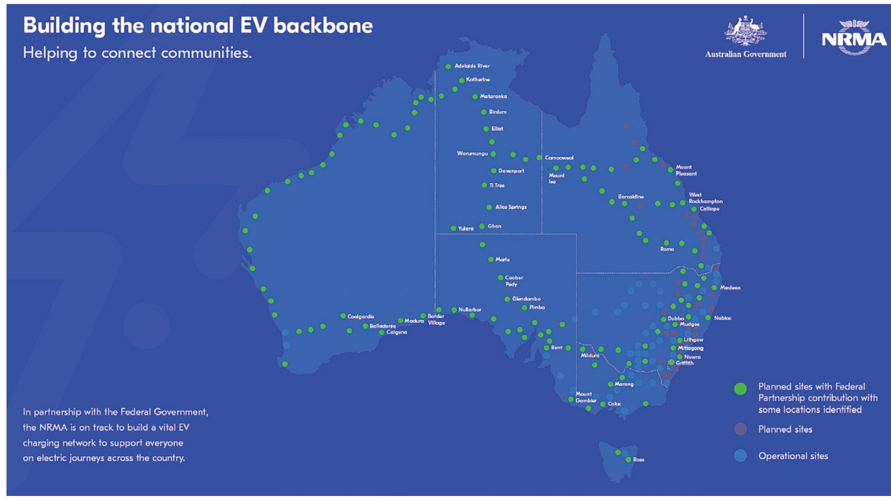
- Increase supply of affordable and accessible electric vehicles;
- Establish the resources, systems, and infrastructure to enable rapid EV uptake; and
- Encourage increased EV demand.

These objectives will be funded largely through the Driving The Nation Fund, which is an ongoing government program developed to enable the demonstration and deployment of new zero-emissions vehicle technologies.

The three key elements of the Driving The Nation Fund are below. Monetary amounts are given in Australian dollars.

- **The National EV Charging Network project** aims to ensure a fast EV charger is available to drivers approximately every 150 kilometers (93 miles) on the national highways. The government is partnering with the Australian automobile association NRMA to build 117 new fast EV charging sites with $39.3 million in funding.
- **The Hydrogen Highways project** claims to help states and territories decarbonize heavy transport. Up to $10 million will be provided to all jurisdictions on a matched basis (up to $80 million total) to help industry fleets acquire heavy hydrogen fuel cell vehicles and construct renewable hydrogen refueling stations, located on major freight routes across Australia.
- **Australian Renewable Energy Agency (ARENA) grants** will provide more than $130 million to co-fund initiatives that will reduce Australia's road transport emissions by improving access to advanced EV charging infrastructure. For example, grants are expected to deliver charging solutions for those living in apartment blocks or remote communities.

"EVs aren't just for the cities, and Australians who drive long distances either for work or for holidays should be able to



Credit: Australian Government and NRMA

The Australian government is partnering with the Australian automobile association NRMA to build 117 new fast EV charging sites across the country.

reap the benefits of cars that are cheaper and cleaner to run," says Australian Minister for Climate Change and Energy Chris Bowen in a press release.

Visit https://www.dcceew.gov.au/energy/transport/national-electric-vehicle-strategy to learn more about the strategy. ■

SOCIETY
DIVISION
SECTION
CHAPTER
NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners:

Laeis GmbH

Kopp Glass, Inc

Minchem Limited

Samuel Packaging Systems Group

Sumitomo Chemical Co., Ltd.

To learn about the benefits of ACerS Corporate Partnership, contact Marcus Fish, industry relations director, at (614) 794-5894 or mfish@ceramics.org. ■

Central Ohio Section holds clay throwing event

The Central Ohio Section held its first annual clay throwing event on May 19, 2023, at the Hands-On Art Barn in Galena, Ohio. ACerS members received instruction on how to make a clay product using the wheel. ■

ACerS members at the clay throwing event in Galena, Ohio.

Attend your Division business meeting at MS&T23

Six of ACerS Divisions will hold executive and general business meetings at ACerS Annual Meeting at MS&T23 in Columbus, Ohio. General business meetings will be held Monday or Tuesday in the Greater Columbus Convention Center. Plan to attend to get the latest updates and to share your ideas with Division officers.

Monday, Oct. 2

Glass & Optical Materials Division: 11 a.m.–12 p.m.
Electronics Division: Noon–1 p.m.
Engineering Ceramics Division: Noon–1 p.m.
Bioceramics Division: 2–2:30 p.m.
Energy Materials and Systems Division: 5:30–6:30 p.m.

Tuesday, Oct. 3

Basic Science Division: Noon–1 p.m. ■

FOR MORE
INFORMATION:

ceramics.org

ACerS Italy International Chapter co-organized 10th KMM-VIN Industrial Workshop

The ACerS Italy International Chapter collaborated with the European Virtual Institute on Knowledge-based Multifunctional Materials (KMM-VIN) to successfully organize the 10th KMM-VIN Industrial Workshop "Advanced materials for energy: challenges and opportunities." The workshop took place at Politecnico di Torino, Italy, on May 11–12, 2023.

Under the coordination of Politecnico di Torino professor Federico Smeacetto and other university colleagues, the workshop provided a platform for renowned experts from both industry and academia to engage in discussions regarding the latest advancements in the field of advanced materials for energy and associated technologies. The event attracted a substantial number of attendees, with more than 50 active participants, including senior and young researchers, industry professionals, and students.

The Chapter generously sponsored poster awards, recognizing exceptional contributions in the field. The winners of these awards were

First place: **C. Malinverni**, Politecnico di Torino, Italy

Joining of ceramic matrix composites that operate under extreme conditions using glass-ceramics

Second place: **G. H. O. Marcatto**, TU Graz, Austria

Fully additive manufacturing of PC/AlSi10Mg hybrid joints with surface structured substrate: a promising approach for lightweight applications

Third place: **E. Zanchi**, Politecnico di Torino, Italy

Integration of glass-based sealings with metallic interconnects in solid oxide cell stacks ■

ACerS president-elect Monica Ferraris, right, with ACerS member Federico Smeacetto.


Award winners, left to right: E. Zanchi, C. Malinverni, and G.H.O. Marcatto.


Attendees of the 10th KMM-VIN Industrial Workshop at Politecnico di Torino, Italy.

IN MEMORIAM

William Evans

Robert Ingel

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

more SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS International Chapters

Welcome to the newest ACerS International Chapters! The ACerS Board of Directors recently approved a petition to establish Chapters in the following countries.

Nordic Chapter

The Nordic Chapter will encompass Denmark, Finland, Iceland, Norway, and Sweden.

Chapter officers are

Chair: **Yogendra Kumar Mishra**, University of Southern Denmark
Treasurer: **Sandeep Thouti**, University of Southern Denmark
Secretary: **Gunnar Weston**, Uppsala University

Turkey Chapter

Chapter officers are

Chair: **Ender Suvaci**, Eskisehir Technical University
Treasurer: **Ayşe Tunalı**, VitrA
Secretary: **Caner Durucan**, METU

India Chapters

Additionally, the **ACerS India Chapter** has been split into two regional chapters: the Northeast India Chapter and the Southwest India Chapter.

The **Northeast Chapter** will include Uttar Pradesh; Haryana; Delhi; Punjab; Himachal; Pradesh; Rajasthan; Gujarat; Jammu & Kashmir; Bihar; West Bengal; Tripura; Meghalaya; Orissa; Manipur; Nagaland; Uttarakhand; Chhattisgarh; Madhya Pradesh; Daman; Diu; Chandigarh; Arunachal Pradesh; Jharkhand; Assam; Mizoram; and Sikkim.

The officers of the **Northeast Chapter** are

Chair: **Lalit Kumar Sharma**, Mahanana Ceramic Development Organizational
Treasurer: **Preeti Kumari**, IIT (BHU)
Secretary: **Asha Anil**, Central Glass and Ceramic Research Institute

The **Southwest Chapter** will include Andhra Pradesh; Telangana; Karnataka; Tamil Nadu; Pondicherry; Goa; Kerala; Maharashtra; Lakshadweep; and Andaman Nicobar.

The officers of the Southwest Chapter are

Chair: **C. D. Madhusoodana,** Bharat Heavy Electricals Limited
Treasurer: **S. Chandrashekar**, Saptha Group
Secretary: **Ravi Kumar**, Indian Institute of Technology Madras

Contact Vicki Evans at vevans@ceramics.org for more information about these new Chapters or to form a Chapter in your region. ■

Ceramic Tech Chat: Chris Heckle

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 third Wednesday of each month.

In the May 2023 episode of Ceramic Tech Chat, Chris Heckle, director of the new Materials Manufacturing Innovation Center at Argonne National Laboratory, talks about how the national labs contribute to the innovation ecosystem, overviews the research that takes place at Argonne specifically, and describes how the new Center aims to improve and expand the labs' support for industry.

Check out a preview from her episode.

"[The labs] invest in capabilities that companies need only occasionally, and therefore they can't afford to maintain. And so Argonne as well as a couple of other labs have user facilities where a company can apply to do work essentially for free as long as they're willing to have the work published at a national lab."

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

Volunteer spotlight

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

Young-Wook Kim is professor of materials science and engineering at the University of Seoul, Republic of Korea. He received an M.S. and Ph.D. in materials science and engineering from the Korea Advanced Institute of Science and Technology and a B.S. in ceramic engineering from Yonsei University. Before joining the University of Seoul in 1996, he worked as a senior research scientist at the Korea Institute of Science and Technology.

Kim has authored or co-authored more than 330 journal articles and holds about 60 issued patents. He is an academician from the World Academy of Ceramics, a fellow of ACerS, and an honorary fellow of the European Ceramic Society. He received the John Jeppson Award, Samuel Geijsbeek PACRIM International Award, Global Star Award, and Global Ambassador designation from ACerS.

In addition to being a founding member of the ACerS Korea Chapter, Kim is chair-elect of the Engineering Ceramics Division and editor-in-chief of *International Journal of Applied Ceramic Technology*.

Shiho Kawashima is associate professor of civil engineering and engineering mechanics at Columbia University, N.Y. Her core areas of expertise are in cement and concrete, with a focus on rheology and processing, materials characterization, and alternative cements/clinkers. She received her B.S. in civil engineering and engineering mechanics at Columbia University, and her M.S. and Ph.D. in structural engineering and materials at Northwestern University. She joined Columbia University as an assistant professor in 2013.

Kawashima is an active member of ACerS, serving as past president of the Cements Division and co-chair of the 2022 and 2023 Annual Meetings. She is also an active member in the American Concrete Institute (ACI) and the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM). She serves on the editorial board for the American Society of Civil Engineers' *Journal of Materials in Civil Engineering*, ASTM's *Advances in Civil Engineering Materials, Cement and Concrete Research, ACI Materials Journal, and RILEM Technical Letters*.

Kawashima received an NSF CAREER Award on the topic of 3D concrete printing in 2017 and the ACerS Cements Division Early Career Award in 2022.

We extend our deep appreciation to Kim and Kawashima for their service to our Society! ■

Names in the news

Mrityunjay Singh, FACerS, DLM, chief scientist at the Ohio Aerospace Institute, was recognized with a third Honorary Doctorate from AGH University in Krakow, Poland (pictured). He also received the NASA Outstanding Public Leadership Medal at NASA Glenn.

Deborah D.L. Chung, professor in the Department of Mechanical and Aerospace Engineering at the University of Buffalo, was named a Fellow of the American Academy of Arts and Sciences.

Cato T. Laurencin, FACerS, Albert and Wilda Van Dusen Distinguished Endowed Professor of Orthopaedic Surgery and professor of chemical and biomolecular engineering, materials science and engineering, and biomedical engineering at the University of Connecticut, was named the recipient of the Inaugural DEI Award of the Society for Biomaterials. ■

AWARDS AND DEADLINES

2024 Class of Fellows nominations: Deadline is Jan. 15, 2024

The 2024 Class of Society Fellows recognizes members who have made outstanding contributions to the ceramic arts or sciences through productive scholarship or conspicuous achievement in the industry or by outstanding service to the Society. Nominees shall be people of good reputation who have reached their 35th birthday and who have been members of the Society at least five years continuously. Questions may be directed to **Erica Zimmerman** at ezimmerman@ceramics.org.

Do you qualify for Emeritus membership?

If you will be 65 years old (or older) by **Dec. 31, 2023**, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact **Erica Zimmerman** at ezimmerman@ceramics.org.

Society Awards	Nomination Deadline	Contacts	Description
Darshana and Arun Varshneya Frontiers of Glass Lectures	Sept. 1	Erica Zimmerman ezimmerman@ceramics.org	Lectures are designed to encourage scientific and technical dialogue in glass topics of significance that define new horizons, highlight new research concepts, or demonstrate the potential to develop products and processes for the benefit of humankind.
Society Fellows	Jan. 15	Erica Zimmerman ezimmerman@ceramics.org	Recognizes members who made outstanding contributions to the ceramic arts or sciences through productive scholarship or conspicuous achievement in the industry or by outstanding service to the Society.

Division	Award	Nomination Deadline	Contacts	Description
BSD	**Graduate Excellence in Materials Science (GEMS)**	Aug. 4	John Blendell blendell@purdue.edu	Recognizes the outstanding achievements of graduate students in materials science and engineering. Open to all graduate students who will present an oral presentation in any symposium or session at the Materials Science & Technology (MS&T) meeting.
BSD	**Roland B. Snow/ Ceramographic Competition**	Sept. 20	Klaus van Benthem benthem@ucdavis.edu	Presented to the Best of Show winner of the Ceramographic Exhibit & Competition, an annual poster exhibit to promote the use of microscopy and microanalysis in ceramic research.

STUDENTS AND OUTREACH

FOR MORE INFORMATION:

ceramics.org/resources-for-students

Material Advantage student competitions

Learn more about each contest and find out how to enter at https://bit.ly/MSTstudentactivities.

Undergraduate Student Poster Contest

The Undergraduate Student Poster Contest provides an opportunity for students to put their communication skills to work by presenting their undergraduate research.

Cash prizes will be awarded in the amounts of $250, $150, and $100. All undergraduate students may participate. To enter, submit an abstract of no more than 150 words by **Sept. 1, 2023**, to the symposium titled “2023 Undergraduate Student Poster Contest” at http://bit.ly/2023undergradposters.

Undergraduate Student Speaking Contest

The Undergraduate Student Speaking Contest provides an opportunity for students to showcase their presentation skills by making a short technical presentation about an aspect of materials science and engineering that they find exciting.

Cash prizes will be awarded in the amounts of $500, $250, $150, and $100. Up to two students per university may participate. Contestants must be reported to Yolanda Natividad by **Sept. 8, 2023**.

Graduate Student Poster Contest

The Graduate Student Poster Contest recognizes superior research performed during graduate study.

Cash prizes will be awarded in the amounts of $250, $150, and $100. Only those graduate students who have an accepted poster abstract at MS&T are eligible to enter. Contestants must be reported to Yolanda Natividad at ynatividad@ceramics.org by **Sept. 1, 2023**. ■

ACerS GGRN for young ceramic and glass researchers

GLOBAL GRADUATE RESEARCHER NETWORK
THE AMERICAN CERAMIC SOCIETY
CERAMICS.ORG/GGRN

ACerS Global Graduate Researcher Network (GGRN) addresses the professional and career development needs of graduate-level research students who have a primary interest in ceramics and glass.

GGRN helps graduate students

- Engage with ACerS,
- Build a network of peers and contacts within the ceramic and glass community, and
- Access professional development tools.

Are you a current graduate student who could benefit from additional networking within the ceramic and glass community? Visit www.ceramics.org/ggrn to learn what GGRN can do for you, or contact Yolanda Natividad, ACerS membership engagement manager, at ynatividad@ceramics.org. ■

#YoungProPerks

Are you a recent graduate? Let ACerS help you succeed with a free one-year Associate membership! Sign up at www.ceramics.org/associate. ■

CERAMICANDGLASSINDUSTRY FOUNDATION

CGIF Kit Grant recipient connects materials science to medicine with the Young Surgeons Club

Cameron Stuart (center, gray shirt) pictured with students in the Young Surgeons Club.

At first glance, one may not realize what a cow heart and materials science have in common. But as students in the Young Surgeons Club watch as a cardiologist inserts a stent into a cow heart, it mimics a real-life procedure that opens a clogged artery and echoes the Ceramic and Glass Industry Foundation's (CGIF) shape memory alloy lesson.

The lesson demonstrates how temperature changes, like insertion into the body, can allow materials like nitinol to expand into its original shape and hold up the walls of a collapsed or clogged artery.

The Young Surgeons Club is an after-school organization where seventh and eighth grade students at University School in Shaker Heights, Ohio, learn about medical professions through a series of discussions and demonstrations led by medical professionals from various fields.

Young Surgeons Club advisor and sixth grade science teacher Chris Ann Slye first made the connection between materials science and the medical field after attending the CGIF's Teacher Training Workshop in summer 2022.

Slye received a CGIF kit grant so she can incorporate Mini Kit lessons, such as "What is a Shape Memory Alloy?", into the Young Surgeons Club, as well as the sixth grade Blood and Guts Club she sponsors.

"It was really nice to not have to spend the school money and instead have that support, which then motivated me even more to just keep finding connections between what was in the kit and how I can apply that to my curriculum," Slye says.

In the spring, she invited her husband and GrafTech materials scientist Bill Slye to speak at a Young Surgeons Club meeting. Bill Slye focused his talk on different materials, with an emphasis on the metal alloy nitinol, and then Chris Ann Slye taught the shape memory alloy lesson to her students.

During an application of this lesson, Samir Kapadia, chairman of the Department of Cardiovascular Medicine at the Cleveland Clinic, demonstrated an angioplasty for the Young Surgeons. An angioplasty is a procedure that opens a clogged or blocked artery.

Kapadia inserted a stent to support the artery, which connects to the shape memory alloy lesson by showing how materials such as nitinol can be manipulated for use in medical applications. Stents can be made out of metal mesh, silicon, or combinations of other materials, depending on where they are inserted in the body. Kapadia used a cow heart to conduct the stent insertion so students could see and assist in a hands-on demonstration.

"They love the hands-on component. And when you do it, you learn it," Slye says. "So even though it may be an abstract or higher-level concept that you're trying to teach them, they get it if they do it."

Stuart talked with students about medical school and anesthesiology during a Young Surgeons Club meeting.

In addition to the shape memory alloy lesson, Slye has also utilized the CGIF Glass Kit lesson "Water Pods: Bioactive Glass Microbead Encapsulation" to teach the Young Surgeons Club about drug delivery in medicine and pharmaceuticals. The glass microbead lesson teaches students about the concept of liquid encapsulation within spheres and how they can break down in the body through the safety of water pods instead of medicine.

Slye invited Cameron Stuart, an anesthesiologist from Cleveland Clinic, who gave a presentation about medical school and anesthesiology at another Young Surgeons Club meeting. She then taught a lesson inspired by the CGIF's bioactive glass microbead lesson to connect Stuart's talk about anesthesiology with drug delivery and bioactive glasses.

"I just thought this would be the perfect tie-in to merge my love of engineering—because my background is chemistry—with the Young Surgeons medical concepts," she says. "So the two lessons just really tied in very well."

Slye's main goal for the Young Surgeons Club is to plant "science seeds" in the minds of students so that they may be inspired to pursue fields in materials science or explore careers in engineering disciplines such as biomedical engineering.

"Not everybody's going to go on and be a medical doctor or follow a medical profession, but a lot of people end up going off to different disciplines of engineering," she says. "I think students don't quite understand all their engineering options… Usually materials science is not even remotely in their brain. I feel that materials science is that perfect crossover between medicine, between chemistry, between everything." ■

ESG trends in the mining industry: Critical steps to achieving pledged targets

By BCC Publishing Staff

The world is undergoing an era-defining shift to a low-carbon, sustainable economy.

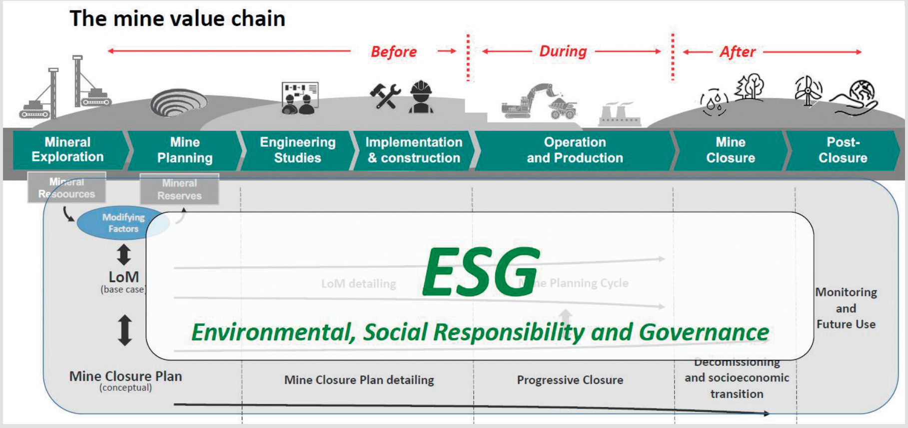
This shift puts mining companies in an unprecedented financial position to take a significant, risky turn for the better by adopting environmental, social, and governance (ESG) practices.

ESG is a framework to help mining firms raise environmental standards as well as be more active and more beneficial participants in local and regional communities. Several top 40 mining companies have already made ESG-related pledges, such as by setting greenhouse gas emission reduction goals (Table 1).

For mining companies to realize their pledged ESG initiatives, there are several critical steps they must take.

Changing established value chains. Mining companies are reassessing their mineral holdings to include climate-friendly minerals and creating partnerships with downstream industries, such as automobile manufacturing. New circular business models that rely on urban mining, recycling, or metal reprocessing are also taking shape.

Thinking outside the sustainability box. The mining sector should avoid considering sustainability only in terms of its benefit but also as decisions that can provide value. For example, ESG or decarbonization strategies can raise efficiency, increase stakeholder confidence, and lower cost curves for energy use.



Credit: Giorgio de Tomi, "ESG challenges for small-scale mining in the 21st century," University of São Paulo, July 2022

Figure 1. ESG throughout the mine value chain.

Integrating ESG into organizations. Publicly stated ESG goals and commitments at the board level are insufficient to encourage execution. To move ESG practices from pledge into action, mining businesses need to establish a clear governance structure and an operational model that promotes responsibility, visibility, and departmental collaboration throughout the entire company (Figure 1).

Encourage flexibility and openness. Integrating ESG practices is a learning process, and adjustments will be needed. Systems will be required to illuminate the effectiveness of ESG initiatives. For example, companies may establish new positions or channels of communication that can provide updates on the ESG's development.

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, "ESG trends in mining industry" BCC Research Report ENV062A, March 2023. www.bccresearch.com.

Table 1. Key greenhouse gas emissions targets for selected mining and metals companies

Company	2030	2035	2040	2050	Greenhouse gas protocols
Anglo American	At least 30% reduction in net-GHG emissions (vs. FY16) and 30% improvement in energy efficiency		Carbon neutrality (Scope 1 and 2) across all operations		*Scope 1: Direct emissions that are under the operational control, such as fleet vehicles* *Scope 2: Indirect emissions from electricity purchased by the mining operation* *Scope 3: All other indirect emissions from activities that the mining company does not own or control, such as emissions associated with the steel industry that is consuming iron ore*
Barrick Gold	At least 30% reduction in GHG emissions (vs. FY18)			Net-zero GHG emissions	
BHP	At least 30% reduction in operational GHG emissions (vs. FY20)			Net-zero operational GHG emissions	
FMG	Net-zero Scope 1 and 2 GHG emissions across existing and future operation				
Glencore	At least a 30% reduction in Scope 1 and 2 absolute GHG emissions and emissions intensity (vs. FY18)			Net-zero total GHG emissions	
Newmont		At least 40% reduction in GHG emissions (vs. FY19)		Net-zero GHG emissions	
Rio Tinto	Reduce absolute GHG emissions by 15% and emissions intensity by 30% (vs. FY18)			Net-zero GHG emissions	
Vale	Reduce absolute Scope 1 and 2 GHG emissions by 33% (vs. FY17)	Reduce Scope 3 net emissions by 15% (vs. FY18)		Carbon neutrality (Scope 1 and 2)	

Freely available deep learning method ‘fills in the blank’ of unknown internal material structures

Doctoral student Zhenze Yang and professor of civil and environmental engineering Markus Buehler at Massachusetts Institute of Technology developed a deep learning method that predicts the internal microstructure of a material based solely on data about the material’s exterior surface conditions.

In an MIT press release about the method, Buehler explains that materials engineering tasks are often hindered by limited information.

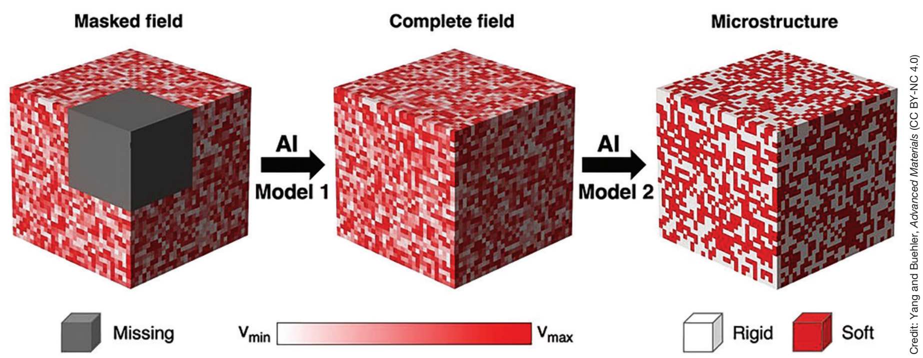
“If you have a piece of material—maybe it’s a door on a car or a piece of an airplane—and you want to know what’s inside that material, you might measure the strains on the surface by taking images and computing how much deformation you have. But you can’t really look inside the material. The only way you can do that is by cutting it and then looking inside and seeing if there’s any kind of damage in there,” he says.

Nondestructive analysis techniques, such as radiographic testing, can provide information about the internal microstructure. However, such techniques can be expensive and often require bulky equipment, limiting the use of these techniques to evaluate materials in the field.

In recent years, the development of deep learning methods to model materials systems provides new opportunities to perform materials analysis and characterization with limited information.

The new method developed at MIT generates internal microstructure predictions by combining multiple deep learning architectures. Specifically,

1. An artificial intelligence mode is first trained to “fill in the blank” (recover complete field information from a partial field) by using vast amounts of data about surface measurements and the interior properties associated with them.
2. A second artificial intelligence model then “solves the puzzle,” i.e., uses the recovered complete field information as input to reversely obtain the corresponding microstructure.



General schematic of the deep learning method developed by the MIT researchers to predict a material’s internal microstructure based solely on its external surface characteristics. An AI model fills in the unknown parts of a partial field (gray box) while a second AI model uses the recovered complete field information to reversely obtain the corresponding microstructure.

In an open-access paper describing the model, Yang and Buehler showed it generated excellent predictions for heterogeneous composite microstructures under both 2D plane strain and 3D bulk cases.

In the MIT press release, Yang notes that the method is broadly applicable.

“It is not just limited to solid mechanics problems, but it can also be applied to different engineering disciplines, like fluid dynamics and other types,” he says.

Buehler adds that it can be applied to determining a variety of properties, not just stress and strain but fluid fields or magnetic fields as well.

“[The method is] very universal, not just for different materials, but also for different disciplines,” he says.

All data and codes used for this study are freely available for anyone to use through GitHub at https://github.com/lamm-mit/FieldCompleter.

The open-access paper, published in *Advanced Materials*, is “Fill in the blank: Transferrable deep learning approaches to recover missing physical field information” (DOI: 10.1002/adma.202301449).

Research News

Shining potential of missing atoms

University of Vienna researchers showed that single atoms can be kicked out of hexagonal boron nitride using a scanning transmission electron microscope under ultrahigh vacuum. Until now, transmission electron microscopy measurements of hBN have been conducted at relatively poor vacuum conditions, leading to rapid damage. Due to this limitation, it was not clear whether vacancies—single missing atoms—could be controllably created. In the future, it may be possible to use electron irradiation to purposefully create specific vacancies that emit single photons of light by selectively irradiating the desired lattice sites with a focused electron probe. For more information, visit https://medienportal.univie.ac.at/en/media/recent-press-releases.

Physicists discover a new switch for superconductivity

Massachusetts Institute of Technology physicists identified the key to how iron selenide undergoes a structural shift known as “nematic transition” to unlock superconducting behavior. In other iron-based superconducting materials, scientists have observed that this shift occurs when individual atoms suddenly shift their magnetic spin toward one coordinated, preferred magnetic direction. However, in iron selenide, the atoms undergo a collective shift in their orbital energy rather than their spins. This fine distinction opens a door to discovering unconventional superconductors. For more information, visit https://news.mit.edu.

Uncovering secrets of the moon—the role of glass beads in the lunar surface water cycle

Thanks to new lunar samples brought back by the Chinese Chang'e 5 lunar exploration mission, researchers in China were able to show that impact glass beads appear to play a significant role in the lunar surface water cycle.

Even before humans first landed on the moon in 1969, scientists suspected there may be water lurking somewhere on the celestial body. In 1998, a neutron spectrometer on board NASA's Lunar Prospector mission confirmed the existence of ice at the lunar poles.

Other missions during the past two decades provided further confirmation of water on the moon. Yet "the origin(s) of this lunar surface water and its spatial distribution and evolution during regolith gardening remain largely unknown, despite key implications for future lunar surface exploration," the researchers write in their open-access paper.

It is generally believed solar wind plays a major role in the presence of water on the moon. Solar wind is a continuous stream of charged particles released from the sun that permeates the solar system. When these charged particles reach the lunar surface, they interact with other atoms—particularly oxygen—to produce hydroxyl or water in lunar soils. Researchers suspect this water then migrates to polar regions, driven by oscillations in temperature.

For this theorized water cycle to be sustained, there would need to be a hydrated layer (reservoir) below the lunar surface.

"However, finding this water reservoir has remained elusive ... [and consequently] there must be a yet-unidentified water reservoir in lunar soils that has the capacity to buffer a lunar surface water cycle," the researchers write.

In 2020, China launched Chang'e 5, the fifth lunar exploration mission of the Chinese Lunar Exploration Program and the country's first lunar sample-return mission. The spacecraft successfully returned about 3.8 pounds (1.7 kg) of lunar samples back to Earth.

Included in the lunar samples were impact glass beads, or tiny glass spheres that form when asteroids or other impactors smash into the moon. Water can accumulate within these glass beads like a sponge, and thus the beads are potential candidates for playing a significant role in the lunar surface water cycle.

The researchers characterized the impact glass beads using petrography, major element composition, Raman characteristics, water abundance, and hydrogen isotope composition.

Their analysis showed that water retained within the impact glass beads originated from the solar wind. This finding supports the theory that solar wind is the main source of water on the moon, in contrast to other potential lunar water sources, such as lunar volcanism or carbonaceous chondrites.

The researchers then proposed a model to explain the potential role of impact glass beads in the lunar surface water cycle (see figure).

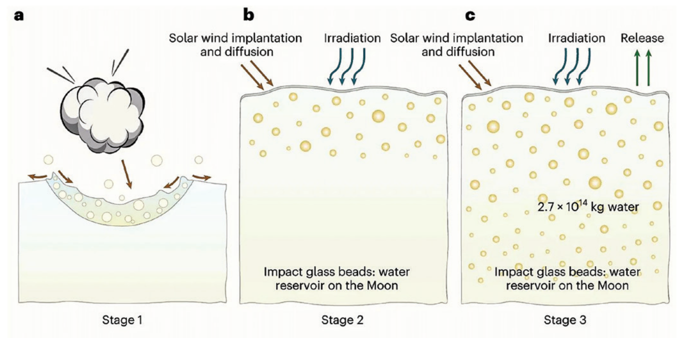


Illustration of the potential role of impact glass beads in the lunar surface water cycle. a) Because of the high temperature of formation of impact glass beads, most water present in precursor materials would have been lost. b) After their deposition at the surface, solar wind-derived water would diffuse into impact glass beads after solar wind hydrogen implantation. c) "Gardening," i.e., the process by which impact events stir the outermost crust of the moon, would transfer the impact glass beads deeper into the soils, creating a water reservoir at the subsurface of the moon. The impact glass beads at the surface would still be able to release water into the lunar exosphere, due to meteoroid impact, for example.

The researchers estimate there to be 3–27 trillion kg of water held by impact glass beads in lunar soils. This water, which they believe could be easily extracted through a heating process to release vapor, provides "a much higher amount of solar wind-derived water than previously thought, which could be a water reservoir for in situ utilization in future lunar exploration," they write.

The open-access paper, published in *Nature Geoscience*, is "A solar wind-derived water reservoir on the Moon hosted by impact glass beads" (DOI: 10.1038/s41561-023-01159-6). ■

Flame-resistant composite achieves low thermal and high electrical conductivities

Researchers at the University of Bayreuth in Germany created a material that exhibits both extremely low thermal and high electrical conductivities.

Achieving such a capability is extremely difficult in metals. In metals, both electric current and heat transfer are primarily carried by electrons. Because both thermal and electrical conductivity are based on the same transport mechanism, they proportionally increase or decrease together as the temperature changes.

In contrast, ceramics primarily conduct heat through the transport of quantized atomic lattice vibrations called phonons. Because the conductivities are based primarily on different transport mechanisms, there is greater potential for realizing nonproportional values.

Some low-density porous carbon materials are known to exhibit low thermal conductivity and high electrical conductivity, but their thermal stability is not very good. This property limits their application in emerging high-temperature devices, such as solid oxide fuel cells.

In the new paper, the University of Bayreuth researchers overcame the thermal instability of carbon by combining it with a nanosized silicon-based ceramic. They created the flexible carbon/silicon nonwoven composite in three steps.

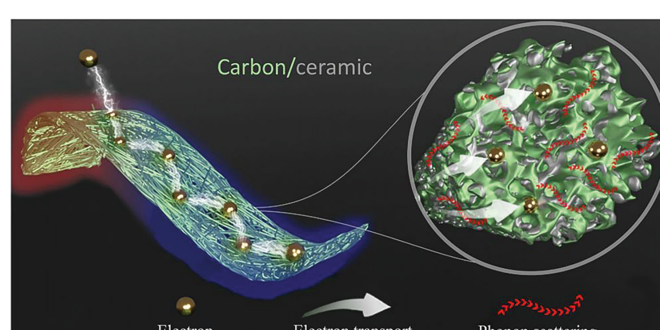
1. Commercial polyacrylonitrile copolymer (PAN) and different amounts of oligosilazane (OSZ) were electrospun to create nonwoven fibers.
2. The fibers were stabilized via a step-wise temperature program or by directly heating from 20° to 250°C under the air atmosphere.
3. The stabilized fibers were then subjected to a carbonization/ceramization heat-treating process in an inert nitrogen atmosphere at 1,000°C for 1 hour, yielding the carbon/silicon nonwoven composite.

The carbon/silicon nonwoven composite featured a sea–island structure, in which the nanosized ceramic phase was homogeneously distributed alongside the carbon phase in every fiber.

The carbon phase modulated the electronic transport, while the ceramic phase induced phonon scattering. These behaviors resulted in low thermal and high electrical conductivities.

The researchers also showed that the carbon/silicon nonwoven composite is flame resistant and very thermally stable. Specifically, it withstood and maintained fiber form even in a 100% O_2 atmosphere during limiting oxygen index tests.

The open-access paper, published in *Science Advances*, is "Extremely low thermal conductivity and high electrical conductivity of sustainable carbon–ceramic electrospun nonwoven materials" (DOI: 10.1126/sciadv.ade6066). ■



Schematic of a flexible carbon/silicon nonwoven composite created at the University of Bayreuth that exhibits low thermal and high electrical conductivities.

Self-sufficient glucose monitoring system successfully manages diabetes in mice

Researchers from ETH Zurich in Switzerland proposed a self-sufficient glucose monitoring system for people with diabetes that not only registers excess glucose but initiates the release of insulin into the blood.

Insulin traditionally is administered through a syringe, injected directly into a layer of fat under the skin. But since the 1980s, people also have the option of using an insulin pump, a small device that automatically delivers small amounts of insulin throughout the day via a catheter, which needs to be changed every few days.

In either case, people need to manually check glucose levels to ensure the administered insulin is keeping blood sugar within the expected range.

Continuous glucose monitoring systems, which automatically track blood glucose levels, could pair with insulin pumps to automatically trigger the delivery of more insulin as needed. These devices may further alleviate the mental burden of diabetes management.

However, currently only a few continuous glucose monitoring systems are FDA approved. And like other bioelectronic devices, there are limitations to powering these systems.

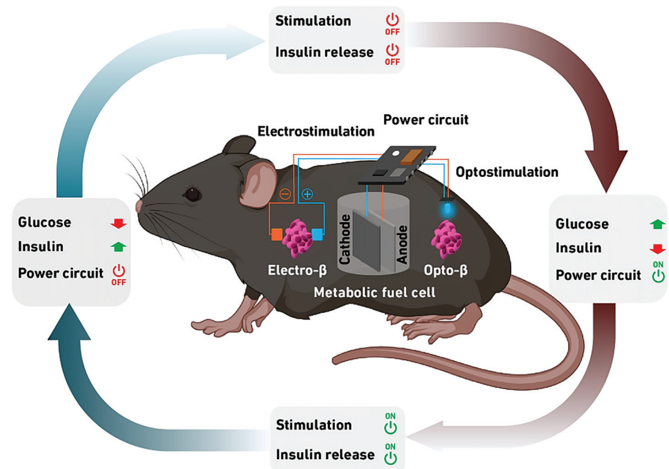
"Currently available bioelectronic devices consume too much power to be continuously operated on rechargeable batteries, and are often powered wirelessly, with attendant issues regarding reliability, convenience, and mobility," the researchers write in their open-access paper. "Thus, the availability of a robust, self-sufficient, implantable electrical power generator that works under physiological conditions would be transformative for many applications."

Their proposed system consists of a fuel cell made from a copper-containing, conductively tuned 3D carbon nanotube composite. The fuel cell is encapsulated in alginate, an algae product approved for medical use, to insulate it from the tissue environment.

The alginate soaks up body fluid and allows glucose to pass from the tissue into the fuel cell. When the fuel cell registers excess glucose, it starts to generate electrical power. This energy is then fed to a capsule containing artificial beta cells, which produce and secrete insulin when stimulated with electricity or blue LED light. Once blood sugar falls below a certain threshold value, the production of electricity and insulin stops.

In addition to triggering insulin production, there is enough electrical energy provided by the fuel cell to enable communication between the implanted system and external devices, such as a smartphone. This connection would allow potential users to adjust the system via a corresponding app, as well as provide doctors with a way to remotely access and adjust the system.

The researchers validated their proposed system by testing the device in mice. However, further advancement of the technology will require an industry partner.



Credit: Maity et al., ETH Zurich

A self-sufficient glucose monitoring system developed by ETH Zurich researchers not only registers excess glucose in blood but initiates the release of insulin, thus helping to manage diabetes.

The open-access paper, published in *Advanced Materials*, is "Blood-glucose-powered metabolic fuel cell for self-sufficient bioelectronics" (DOI: 10.1002/adma.202300890). ■

Done in a flash—advancements in the understanding of flash sintering mechanisms

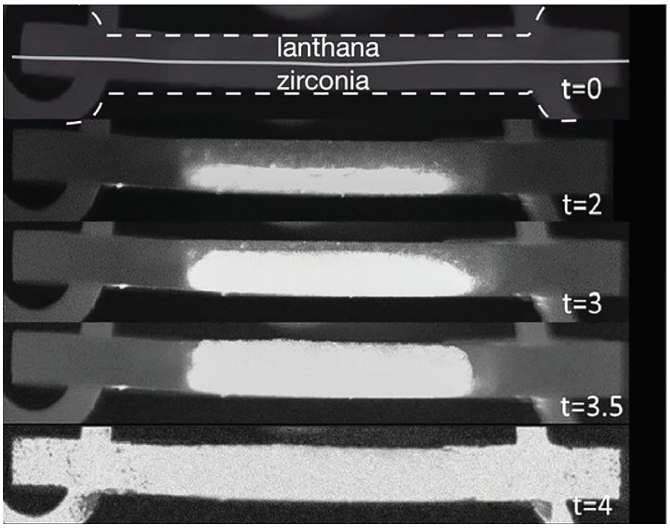
While flash sintering can offer impressive results for manufacturers, the mechanisms and forces driving this process are still not well understood. Four recent articles published in ACerS journals characterize and quantify some of the atomic-level phenomena contributing to the flash sintering of oxide ceramics, namely alumina and zirconia-based oxides.

In these articles, the authors identify five stages of the flash process: heat-up, induction, flash, steady-state, and cool-down.

- During heat-up, the sample is brought to the maximum furnace temperature without applied voltage.
- Induction is the period between application of the voltage field and the initiation of the flash current. When the sample is sufficiently conductive, the flash current initiates.
- During the flash, which occurs on timescales from less than one second to a few seconds, current rises until it reaches or exceeds a preset limit.
- Once flash occurs, the applied voltage is reduced to maintain the current at steady state.
- The final stage is cool-down, where the applied field is shut off and the sample is returned to room temperature via furnace cooling or more rapid methods.

Most researchers focus on doing measurements and modeling during the flash and steady-state phases, though some interesting results have arisen from studying the heat-up, induction, and cool-down stages.

For example, processes such as solid-state reactions of raw materials and the initial stages of sintering have been observed during heat-up. It is believed that atomic-level changes occur during induction, which improve conductivity of the ceramic. Structure coarsening and precipitation of undesirable phases have been observed with slow cooling.



The progression of flash sintering on a lanthana–zirconia bilayer in an 800°C furnace with 300 V/cm field applied and current limited to 100 mA/mm^2.

During the flash phase, processes occur at highly accelerated rates. For example, Yang et al. observed densification changing from about 60% to more than 90% in about 0.5 seconds,[1] while Jalali and Raj measured diffusion coefficients nearly several orders of magnitude greater than that measured during sintering at similar temperatures.[2] Furthermore, activation energies calculated for changes during flash sintering were substantially lower than similar changes for traditional sintering methods.

These studies sought to explain the underlying reasons for these observations and measurements. An obvious possibility is the formation of liquid materials within the flash zone. After all, Joule heating does lead to dramatic increases in temperature. However, the maximum temperatures measured by pyrometer or calculated from black-body radiation models fell below the melting points of pure alumina or yttria-stabilized zirconia, though one open-access study by Aoki et al. showed temperatures above the eutectic point for alumina–gallium aluminate mixtures.[3]

While full conversion of the ceramic to liquid is unlikely, Jalali and Raj point out that increases in the free volume of 3–4% account for similarly high diffusion rates in metals.[2] They cited their and other experiments showing a similar 3–4% volume expansion during flash sintering. They posit a "flash plasma" with spatially dispersed increase in entropy.

Yang et al. discussed contributions from oxygen vacancies and other point defects toward high rates of densification.[4] Using energy dispersive spectroscopy, they determined that alumina lost oxygen atoms during flash sintering, which supports their hypothesis. They further compared activation energies during the flash and during steady-state phases to clarify diffusion mechanisms. Their analysis points to the likelihood that during the flash phase, columbic effects along with very high temperatures lead to grain-boundary diffusion, which drives sintering, while lattice diffusion drives densification during the steady-state phase.

References

[1]Yang et al. "Densification behaviors of Al_2O_3 ceramics during flash sintering," *International Journal of Applied Ceramic Technology*. https://doi.org/10.1111/ijac.14205

[2]Jalali and Raj, "Reactive flash sintering in a bilayer of zirconia and lanthana: Measurement of the diffusion coefficient in real time," *Journal of the American Ceramic Society*. https://doi.org/10.1111/jace.18804

[3]Aoki, Masuda, and Yoshida, "Formation of Al_2O_3–$GdAlO_3$ eutectic ceramics with a fine anisotropic structure in a flash event," *Journal of the American Ceramic Society*. https://doi.org/10.1111/jace.19012

[4]Yang et al., "Flash sintering of ultra-high pure alumina ceramics with fine microstructure," *Journal of the American Ceramic Society*. https://doi.org/10.1111/jace.18554 ■

Researchers refine procedure for printing gradient refractive index optics

In an open-access paper, researchers at the University of Illinois Urbana-Champaign further refined their so-called SCRIBE method for creating gradient refractive index (GRIN) optics.

Researchers have made significant progress over the past two decades in learning how to make GRIN optics. One key to this progress is the 3D-printing technique called direct laser writing, which uses a laser beam to "draw" (solidify) structures within a photoresist (light-sensitive) material.

In 2020, researchers led by University of Illinois Urbana-Champaign professors Lynford Goddard and Paul Braun proposed a unique way to use direct laser writing to achieve even greater control over the refractive index. Their method, called subsurface controllable refractive index via beam exposure (SCRIBE), involves performing direct laser writing inside photoresist-filled nanoporous silicon and silica scaffolds.

"The mesoporous hosts suspend the 3D structures and stabilize the variable fill fraction of the cross-linked photoresist, enabling refractive index control over a broad range ($\Delta n > 0.3$ at visible wavelengths)," they explain in the 2020 open-access paper.

The researchers identified several shortcomings with this technique, some of which they addressed in a follow-up open-access paper published in March 2023.

"We were able to show an improvement from a baseline of 36% to a new value of 49% in the efficiency of fabricated lenses and a clear improvement in the color uniformity resulting from the 2D line gratings we made," says Alexander Littlefield, lead author and graduate student in Goddard's group, in a University of Illinois Urbana-Champaign press release.

They achieved this improvement by making three refinements to the SCRIBE procedure.

1. Using a two-photon fluorescence imaging system to map the photoresist's density. This information allowed the researchers to correctly calibrate the laser power.
2. Modulating the material's position as the laser writes to smooth out errors near the writing boundary.
3. Introducing a time delay between laser exposures to minimize time-dependent effects in the photoresist interaction.

These refinements allowed them to increase the reliable refractive index range from 0.12 to 0.37, plus decrease the standard deviation in the refractive index by up to a factor of 60.

The full data for this paper, including the codes used for calibration and fringe analysis, are available at https://databank.illinois.edu/datasets/IDB-3190140.

The 2020 open-access paper, published in *Light: Science & Applications*, is "Direct laser writing of volumetric gradient index lenses and waveguides" (DOI: 10.1038/s41377-020-00431-3).

The 2023 open-access paper, published in *ACS Photonics*, is "Enabling high precision gradient index control in subsurface multiphoton lithography" (DOI: 10.1021/acsphotonics.2c01950). ■

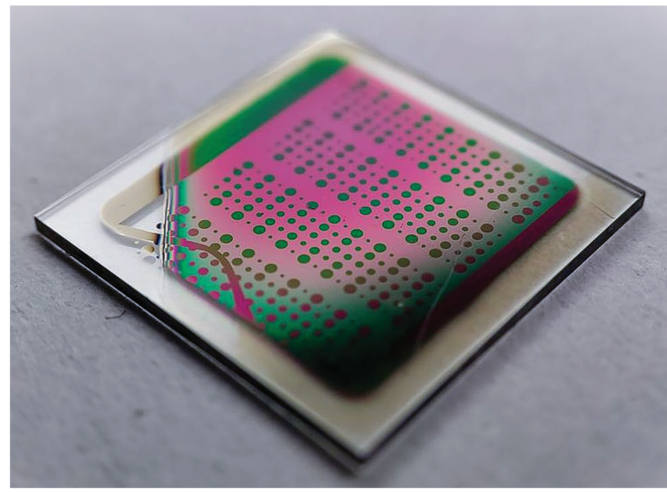
New oxygen-ion battery may be 'excellent' solution for large energy storage systems

In an open-access paper, three researchers from the Vienna University of Technology (TU Wien) in Austria announced a novel solid-state battery composition that may offer certain advantages over other battery technologies—oxygen-ion batteries.

They explain mixed ionic–electronic conducting (MIEC) oxides can conduct both ions and electrons. This ability allows for the incorporation and evolution of oxygen in a manner similar to how lithium-ion batteries store electrical energy through movement of lithium ions.

Despite this similarity, as well as extensive investigations of MIEC oxides as electrode materials in solid oxide fuel cells and solid oxide electrolysis cells, "Systematic investigation of such oxygen insertion electrodes … [to realize] all-solid-state oxygen-ion batteries are not available, to the best of our knowledge," the researchers write.

To test this potential, they fabricated model cells featuring yttria-stabilized zirconia single crystal electrolytes and several different MIEC thin film electrodes. Specifically, the perovskite-type oxides $La_{0.6}Sr_{0.4}FeO_{3-\delta}$ (LSF), $La_{0.5}Sr_{0.5}Cr_{0.2}Mn_{0.8}O_{3-\delta}$ (LSCrMn), and $La_{0.9}Sr_{0.1}CrO_{3-\delta}$ (LSCr).



A prototype of the oxygen-ion battery developed at TU Wien.

Credit: TU Wien

After conducting half-cell measurements on these electrode compositions, they constructed a full oxide-ion battery with an LSF cathode and LSCrMn anode.

DC measurements on the full cell showed capacities as high as 120 mA h cm^{-3} (normalized to the electrode volume) at a cell voltage of 0.6 V at 350–400°C. The cell exhibited excellent cycling performance as well, with less than 1% of the charge being lost per cycle.

Compared to lithium-ion batteries, the oxygen-ion battery only achieved about a third of the energy density, plus it required increased operating temperatures to run (200–400°C). However, neither of these factors play a decisive role in large energy storage applications, and so oxygen-ion batteries could be an "excellent" fit for this purpose, a TU Wien press release reports.

In the press release, first author Alexander Schmid, postdoc in the Institute for Chemical Technologies and Analytics at TU Wien, adds that the oxygen-ion batteries demonstrate another unique advantage—the potential for regeneration.

"In many batteries, you have the problem that at some point the charge carriers can no longer move," he says. "Then they can no longer be used to generate electricity, the capacity of the battery decreases."

The oxygen-ion battery, though, can be easily regenerated. If oxygen is lost due to side reactions, it can be compensated for by oxygen from the ambient air.

The researchers filed a patent application for the oxygen-ion battery together with cooperation partners from Spain. They now are investigating alternative electrode compositions that do not use the rare earth element lanthanum.

The open-access paper, published in *Advanced Energy Materials*, is "Rechargeable oxide ion batteries based on mixed conducting oxide electrodes" (DOI: 10.1002/aenm.202203789). ■

Solid acid fuel cells—a 20-year journey to advancing the hydrogen economy

Hydrogen is emerging as a keystone of many next-generation energy plans, but there are challenges all along the supply chain to realizing a hydrogen economy. For example, even though hydrogen has a high specific energy density, its volumetric energy density is very low. As such, storing or using hydrogen at atmospheric pressure and temperature requires a substantial amount of space.

Hydrogen takes up less space if it is compressed or liquified, but doing so is a technological challenge, especially if the compression/liquification system is meant to be transportable. Instead, converting hydrogen into ammonia (NH_3) allows for easier liquification and storage, and thereby easier transportation.

Yet the ammonia-based approach to hydrogen transportation comes with its own drawback—extracting hydrogen from the ammonia once it reaches its destination. Solid acid fuel cells could be an answer to this obstacle.

Solid acid fuel cells are mid-temperature range fuel cells (~250°C) that use cesium dihydrogen phosphate as the electrolyte. They are the brainchild of Sossina Haile, ACerS Fellow and Walter P. Murphy Professor of Materials Science and Engineering at Northwestern University.

Haile developed solid acid fuel cells in the late 1990s when she was a professor at the California Institute of Technology. When her first Ph.D. student, Calum R. I. Chisholm, graduated, he decided to start a company to commercialize the technology.

Haile and Chisholm initially planned to use the fuel cell to convert hydrogen into electricity, but when the 2008 economic crisis hit, funding for green energy technology dried up. Instead, they secured contracts to use their technology to convert fossil fuels, and this funding solution served as their lifeline for more than a decade.

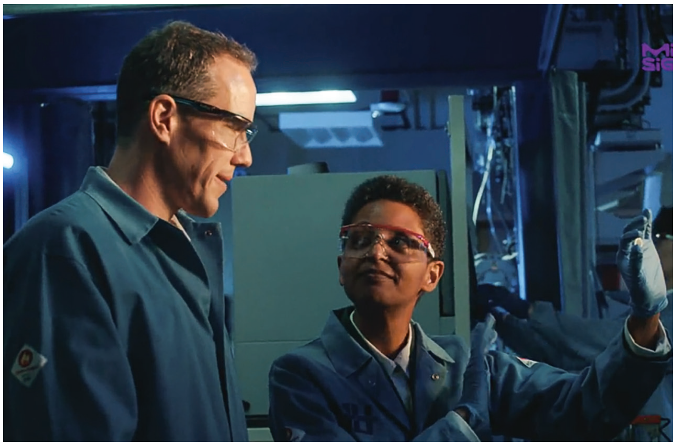
As attention to and funding for hydrogen technologies ramped up again in recent years, Haile realized their fuel cell could be a perfect solution to the hydrogen-from-ammonia extraction problem.

"Ammonia is similar to a dirty fuel because it poisons the catalyst. Our fuel cell can handle poisons. It's tolerant," she says in an interview with MilliporeSigma/Sigma-Aldrich.

Running their fuel cell in reverse, with ammonia and electricity as the inputs, Haile and Chisholm were able to produce pure hydrogen.

Chisholm is working to partner with companies to commercialize this application through his startup SAFCell. More information can be found on the company website at https://safcell.com.

Haile and Chisholm's 20-year journey to realizing the solid acid fuel cell's potential was showcased in a video by MilliporeSigma/Sigma-Aldrich as part of its "Next Great Impossible" initiative. View the video at https://www.sigmaaldrich.com/US/en/life-science/sigma-aldrich. ■



Credit: MilliporeSigma/Sigma-Aldrich

Northwestern University professor Sossina Haile, right, and her previous Ph.D. student Calum R. I. Chisholm, left, reenact their journey to developing and commercializing the solid acid fuel cell in a video by MilliporeSigma/Sigma-Aldrich.

A core sample from the Thacker Pass Project in Nevada, which is an open-pit lithium mine located within the extinct McDermitt Caldera supervolcano.[6]

Credit: Lithium Americas

Lithium: The 21st century 'gold' rush

By Eileen De Guire

The increasing global demand for lithium has governments and companies around the world considering how to ensure enough supply of this valuable metal.

Lithium. Element 3 on the periodic table. The lightest of metals. And a global, multibillion-dollar industry.

Demand for the little element has skyrocketed with burgeoning demand for portable energy, i.e., batteries. Myriad rechargeable devices as varied as laptop computers, cell phones, pacemakers, and power tools use lithium-ion battery (LIB) packs to supply their portable power. But perhaps the biggest devices deploying LIBs are electric vehicles and grid-storage batteries. These devices, especially the former, have eclipsed demand for lithium from every other application.

Batteries are not the only use for lithium. The ceramics and glass industry has long used lithium carbonate as a key raw ingredient for glass-ceramic products with low or near-zero coefficients of thermal expansion. Famously used for cookware, these glass-ceramics also find applications in telescope mirrors and mirror mounts and other applications where thermal stability is critical. Other ceramic and glass uses for lithium include as glaze fluxes, in lithium niobate electro-optic components, and as concrete additives to slow down damaging alkali–silica reactions.

Other uses for lithium include pharmaceuticals, greases and lubricants, continuous casting mold flux agents, and aluminum alloying. The nuclear power industry uses Li-7 isotope additives in pressurized water reactor cooling systems to stabilize pH for corrosion control.

With such a high demand for this metal from so many different industries, governments and companies around the world are concerned about having access to enough supply. For example, most critical materials lists within the International Energy Agency's policies database identify lithium as a strategic, critical mineral.[1]

Lithium minerals market

Lithium sources

Like most raw materials, lithium-containing resources are not distributed evenly across the globe. In its annual *Mineral Commodity Summaries* report,[2] the U.S. Geological Survey estimates there are 26 million tons (Mt) of lithium reserves globally. Chile and Australia are the big winners with 9.6 Mt and 6.2 Mt, respectively. Argentina is positioned to be a major producer with 2.7 Mt of identified reserves. China reports 2 Mt, and the U.S. and Canada combine for 1.93 Mt. Other countries with commercially interesting reserves include Zimbabwe and Brazil. Another 4 Mt are scattered throughout Europe, Africa, and Mexico.

Australia is the largest producer of lithium, which it extracts from lithium-bearing ores, also referred to as "hard-rock" mining.[2] Chile is the second largest producer of lithium, which it extracts from salt flats. (See "Chile and the clean energy transition" on page 26 of this issue.)

Most lithium for commercial applications is sold as lithium carbonate, lithium hydroxide, or lithium chloride. While China is only the third largest producer of lithium, contributing about 13% of global supply, it provides 60% of the world's lithium refining capacity, ensuring its position as a major player in the global lithium economy. Chile provides 29% of the world's refining capacity, while the U.S. holds 3% of global refining capacity at two domestic plants.[3]

But of these lithium reserves, how much is available now, and how much does industry need?

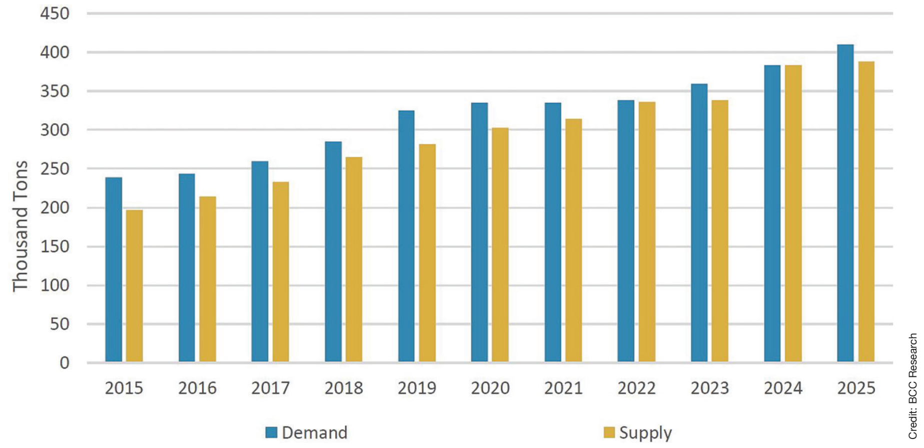


Figure 1. Global demand and supply projections for lithium, 2015–2025.[4]

Supply and demand

The 2023 USGS report states that batteries represent 80% of the lithium market, followed by a distant 7% going to the ceramics and glass industry. Other industries—including lubrication, casting, air treatment, and pharmaceuticals—consume 5% or less each.

So far, supply is keeping up with demand, but barely. According to a 2020 report from BCC Research (Figure 1),[4] in the 10-year period from 2015 through 2025, demand for lithium is expected to grow from about 240 thousand tons to 410 thousand tons, or a 70% increase. Meanwhile, supply is projected to increase from about 195 thousand tons to about 390 thousand tons, or a 100% increase.

These projections may be on the high side. According to the 2023 USGS report, non-U.S. lithium production increased by 21% in the 2021–2022 period from 107 thousand tons to 130 thousand tons. U.S. production (contributing only 0.9% of global demand) grew 41% from 95 thousand tons in 2021 to 134 thousand tons in 2022.

However, with the end of COVID-19 pandemic-related restrictions and increasing government support for lithium mining operations, production may experience larger growth rates in the coming years.

Regardless of the exact tonnages, the trends are clear: Demand is increasing rapidly, and producers are scrambling to keep up.

Lithium pricing

With demand for lithium on the rise, the price per ton is rising, too. As seen in Figure 2,[5] between 2010 and 2015, the USD price per ton for lithium carbonate rose by 72% from $4,00/t to $6,900/t. The market enjoyed a short respite with a modest 4% increase from 2015 to 2016. However, that reprieve proved short lived, with the price more than doubling in only five years to $17,000/t.

The rapidly escalating price of lithium raw materials creates a bind for the ceramics and glass industry. Though lithium is not essential for many commodity-scale products, such as container glass, flat glass, or fiberglass, it is often used in price-sensitive products, such as specialty glasses and glass-ceramics.

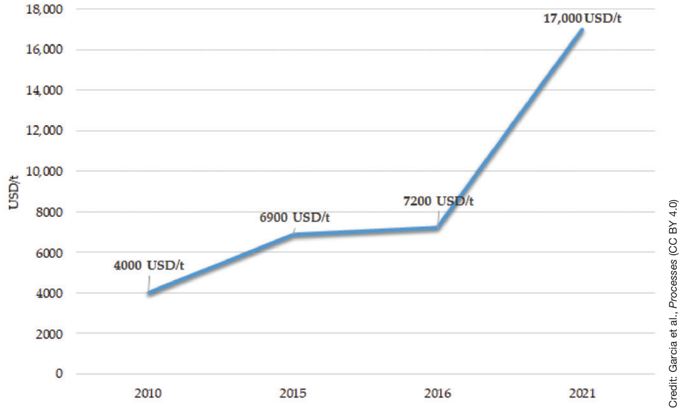


Figure 2. Lithium carbonate price per ton (2010 to 2021).[5]

"It's not true to say that the lithium-bearing minerals cannot be obtained (or are unavailable), they are just painfully expensive," says Scott Cooper, technical director USA of Celsian and president of the Glass Manufacturing Industry Council trade association. "So naturally manufacturers will look for substitutions that can achieve similar performance without the price hit."

For example, lithium is used as a fluxing agent in porcelain enamel formulations. The May 2023 International Enamellers Congress in Kyoto, Japan, included a talk titled "Very low lithium electrostatic powder enamels for major appliances," presented by Charles Baldwin of Vibrantz Technologies (Cincinnati, Ohio).

Cooper suggests another possible consequence of high lithium prices will be a pivot by customers to completely different material systems rather than seeking alternative compositions.

"From what I see, those who are most at risk are glass (or glass-ceramic) products for which there is an alternative, such as plastics, even if the performance is inferior. A rising cost gap will drive more people to the alternative," he says.

Securing lithium: Where can we get more?

With the backing of government incentives and commitment from automakers, the electric vehicle and grid battery storage markets for LIBs appear to be many years away from peaking. That makes investment in developing new lithium mines and production facilities attractive.

North America

In the U.S., Lithium Americas received permits from the State of Nevada in February 2022 for the Thacker Pass Project, an open-pit lithium mine located within the extinct McDermitt Caldera supervolcano.[6] The volcano formed more than 16 million years ago, and a large lake formed in the volcano's collapsed caldera basin. The lake drained during a "late life" volcanic event, which lifted lithium-rich sediment to the surface.

The company reports the site has 37 Mt of lithium carbonate equivalent in reserves, enough to keep the mine producing 80 thousand tons of lithium carbonate annually for about

40 years once it reaches full capacity. Construction began in spring 2023, with production set to begin fall of 2026.

General Motors announced in January 2023 that it is investing $650 million to jointly develop Thacker Pass with Lithium Americas.[7] This deal is the largest battery raw materials investment by an automaker to date.

Also in Nevada is the Bonnie Clair Project, which contains 18.37 Mt of lithium carbonate equivalent.[8] The project is still undergoing geologic evaluation.

In 2021, Rio Tinto opened a demonstration plant in Boron, Calif., to extract lithium from its waste rock piles accumulated over 90 years of borate mining.[9] The demonstration plant is a step toward development of a full-scale lithium production facility. The demonstration plant's production capacity is up to 10 tons per year of "battery grade" lithium. A full-scale plant would have capacity for 5 thousand tons per year, which would be enough to power 70,000 electric vehicles. In 2022, the company opened a spodumene concentration demonstration plant in Sorel-Tracy, Canada, to provide lithium oxide for the battery industry.[10]

Salton Sea in Southern California is the nexus of an area dubbed the Lithium Valley, a play off Northern California's Silicon Valley. Several projects are exploring ways to use geothermal and direct lithium extraction technologies to extract and convert the lithium-laden brine located underneath the lakebed, which a recent report estimates could ultimately provide 600 thousand tons per year of lithium carbonate.[11] The report asserts that direct lithium extraction from brine carries less environmental impact than hard-rock mining and evaporation pond processes.

Recovering lithium from brines involves sophisticated chemistries. Scientists at Oak Ridge National Laboratory, in collaboration with the Department of Energy's Critical Materials Institute at Ames Laboratory, recently published their progress toward developing a low-cost, reusable sorbent that could be used at industrial scales (Figure 3).[12,13]

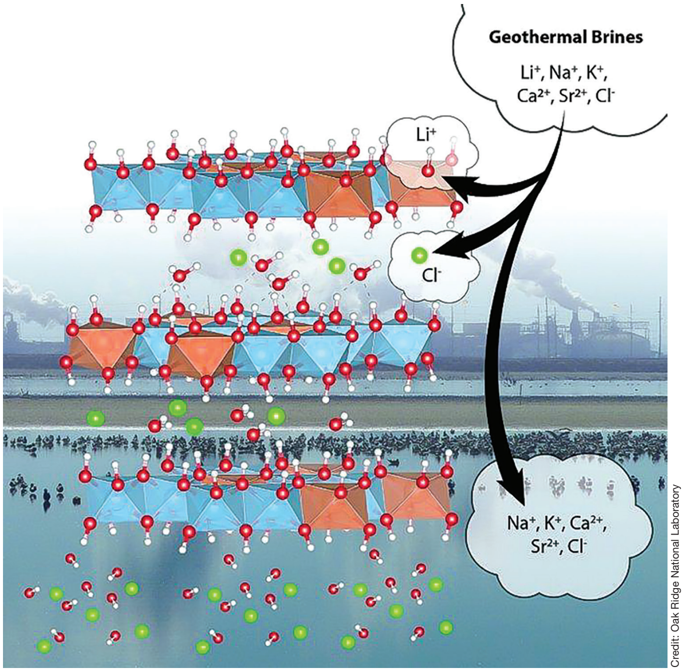


Figure 3. Diagram of lithium-aluminum-layered double hydroxide chloride sorbent.[12]

While developing a domestic lithium supply chain is a national priority for the U.S., each state has autonomy over its mining operations, and some states are less than enthusiastic.

For example, the *Maine Monitor* reported that a couple found a substantial spodumene deposit on their land in western Maine, estimated to hold 11 Mt of ore valued at about $1.5 billion. But in 2022, Maine's Department of Environmental Protection turned down Wolfden Resources' proposal to develop the site, saying the project would have to adhere to the more rigorous metal mining requirements instead of Maine's quarrying requirements.[14]

Europe

Imerys launched a new lithium mining project called EMILI (Exploitation de MIca Lithinifère par Imerys) at its Beauvoir site in Allier, France.[15] According to the company's website, the site will begin production in 2028. The company projects it will be among Europe's largest lithium extraction projects and will provide 34 thousand tons of lithium hydroxide annually for at least 25 years—enough to outfit powertrains for 700,000 electric vehicles each year. Imerys is applying its sustainability commitments to the construction of the mine,[16] and it is designing underground transport systems and water recycling systems for handling ores.

South America

In March 2022, Rio Tinto acquired the Rincon Lithium Project in Argentina, a large undeveloped lithium brine site.[17] A pilot plant with a capacity of 3 thousand tons per year is running on the site. The company plans to use direct lithium extraction technology to minimize the plant's carbon footprint.

In July 2022, Rio Tinto and Ford Motor Company signed a nonbinding memorandum of understanding to jointly develop sustainable supply chains for Ford vehicles.[18] Under the agreement, Ford will explore becoming the foundation customer for the Rincon Lithium Project.

Africa

Significant reserves and growth opportunity lies in Africa, especially in Zimbabwe, which holds the bulk of the continent's lithium reserves. A *Reuters* article reports that Africa is expected to produce 40 thousand tons of lithium in 2023, and it will likely ramp up to 497 thousand tons by 2030.[19] To retain more of the value of the mineral wealth, African countries are demanding that companies and investors build mineral refining operations, too. The *Reuters* article reports that both Zimbabwe and Namibia are putting policies in place to prevent export of raw ores.

Recycling and urban mining

Is battery recycling a viable source of lithium? Absolutely, but it will take 10 years or more for this source to become viable. The reason is simple: There needs to be a large enough supply of spent batteries available for economical recycling.

Joe Lowry, consultant-owner of GlobalLithium.net, wrote in 2021, "Many companies (Redwood Materials, Neometals, Li Cycle, Ganfeng, Umicore, etc.) are in the process of building recycling infrastructure across the globe; however, the fact of the matter is it will take at least a decade, perhaps longer, to have a volume of spent batteries ready to be recycled that will yield sufficient lithium to account for 10 to 15% of total lithium demand."

Until then, Lowry says the demand curve for lithium will be so steep that all sources will need to be deployed: hard-rock mining, brine, sedimentary production, and others.[20]

Finding suppliers: The NAATBatt database

The U.S. Department of Energy's National Renewable Energy Lab has assembled a LIB supply chain database called NAATBatt.[21] The comprehensive end-to-end database was assembled by scouring publicly available resources, searching private and commercial databases, individual questionnaires to more than 800 people, and interviews with selected stakeholders.

The database, which is downloadable in interactive Excel format, provides information on 523 companies at 609 facilities in the U.S., Canada, and other countries, though the majority are U.S.-based entities. The businesses are organized by

- Raw materials manufacturing,
- Battery-grade component manufacturing,
- Other battery components and materials manufacturing,
- Electrodes and cells manufacturing,
- Modules and packs manufacturing,
- End of life/recycling,
- Equipment manufacturing,
- Service and repair,
- R&D,
- Modeling, and
- Distributors.

NREL plans to update the database regularly so that all stakeholders across the supply chain will have reliable information for decision making. It will also serve as a useful benchmarking resource to track the evolution of the LIB supply chain industry over time.

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Salar de Atacama, the largest salt flat in Chile and the third largest in the world. In April 2023, Chilean president Gabriel Boric announced a plan to require that private companies take Chile's government on as a partner in the extraction of lithium.

Chile and the clean energy transition

By Lisa McDonald

As a top producer of copper and lithium, Chile will play a critical role in the clean energy transition. But there are environmental and political obstacles to meeting the demand for these minerals.

The clean energy transition will require unprecedented amounts of minerals.[1] Chile will be a critical player in meeting this demand.

Mining is one of Chile's key economic sectors, accounting for 11% of the country's GDP and more than half of the country's total exports.[2] Among the minerals it produces, Chile is known as the top copper producer in the world and the second-largest producer of lithium,[3] both key minerals in the production of clean energy technologies.

Yet as demand for these minerals surges, Chilean copper mines are struggling. In March 2023, *Bloomberg* reported that Chile had posted its lowest monthly production in six years.[4] While there are recent factors driving this shortage—including a prolonged water drought[5] and a string of operational setbacks and project delays[6]—at least some of the current predicament is historical.

"U.S.-owned mines nationalized by Chilean President Salvador Allende in 1971 weren't returned to their owners after his overthrow two years later in a military coup. Instead, General Augusto Pinochet used them to create Codelco [the Chilean state-owned copper mining company] in 1976. Democratically elected governments since then have milked the state-owned company for cash, which at times has constrained its ability to invest in projects to tap richer veins of its giant deposits," explains a May 2023 *Bloomberg* article on the Chilean copper mining situation.[7]

To overcome these challenges, the *Bloomberg* article reports that left-leaning Chilean president Gabriel Boric agreed to let state-owned Codelco reinvest 30% of its profit, thereby reducing borrowing needs. Additionally, Codelco CEO André Sougarret and chairman Máximo Pacheco are looking to get projects back on track by spreading the load throughout the company, streamlining decision-making, and collaborating with consultants in areas where the company has skills deficits.

Yet Codelco recently added another project to its load that some worry will distract the company from its copper responsibilities—managing public–private lithium partnerships.

Salt flats and ore mines: Understanding lithium sources for clean energy technologies

There are two primary sources for commercial lithium extraction: salt flats and lithium-bearing ores.

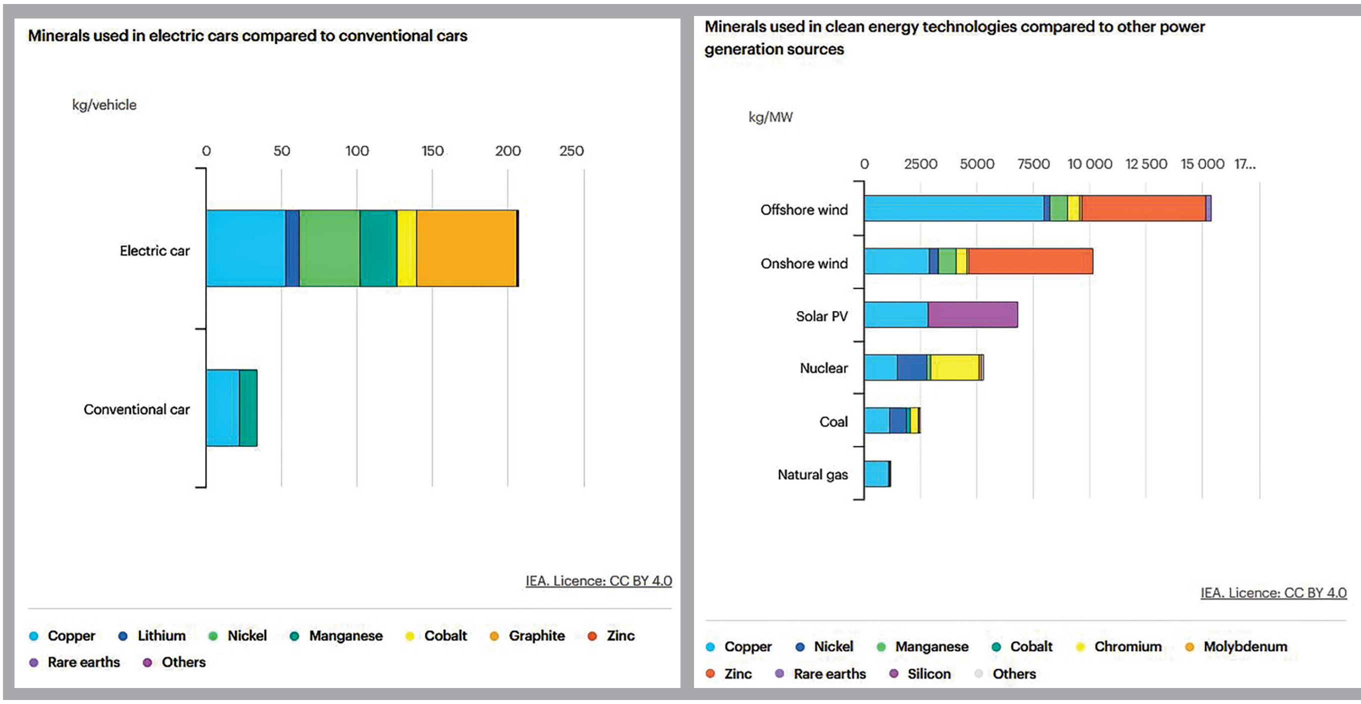
Salt flats, or salars, are areas where lithium-containing saltwater from underground lakes is brought to the surface and evaporated in large basins. This lengthy process, which can take anywhere from several months to a few years to complete, leaves behind concentrated salts from which lithium carbonate can be extracted.

Lithium-bearing ores, such as spodumene, are removed from the earth and processed via crushing, roasting, and acid leaching. This process results in either lithium carbonate or lithium hydroxide.

Australia, the world's top producer of lithium, extracts its lithium through ore mining. Chile, China, and Argentina, the next three largest producers of lithium, mainly extract the mineral from salt flats.

Regarding the clean energy transition, lithium hydroxide is better suited than lithium carbonate for producing battery cathodes because it decomposes at a lower temperature. While lithium carbonate can be converted into lithium hydroxide, doing so requires additional steps and cost. As such, even if Chile increases extraction from its salt flats, the resulting lithium carbonate is not the most sustainable option for meeting this specific demand.

Lithium carbonate is critical, though, in many other applications related to energy infrastructure. For example, as a deoxidizer in the process of industrial copper and nickel smelting and as a starting material in the production of industrial lithium-based grease.



Credit: International Energy Agency (CC BY 4.0)

Lithium mining in Chile

Unlike the copper industry, which Chile nationalized in the 1960s and 1970s, lithium mining in the country is done by private companies, namely U.S.-based Albemarle and Chile's Chemical and Mining Society (SQM).

In April 2023, president Boric announced a plan to require that private companies take Chile's government on as a partner in the extraction of lithium. These public–private partnerships, which would honor existing contracts, would be coordinated by Codelco and state-owned mining company Enami until a national lithium company is created.

This framework for managing lithium projects contrasts with the setups in neighboring Bolivia and Argentina, which together make up the so-called Lithium Triangle. Collectively, these three countries host nearly 60% of the world's known resources of lithium.[8] Chile's approach falls in between the models of Bolivia, in which the state has full control of the lithium sector, and Argentina, in which the state simply grants concessions for companies to operate.

A *Reuters* article reports that Albemarle and SQM have both held preliminary meetings with Chile's state development office about the new lithium framework.[9] However, while SQM signaled it plans to begin serious negotiations soon for its contract, which expires in 2030, Albemarle signaled it will not begin negotiations until closer to its contract expiration in 2043.

In response to concerns about its new lithium role distracting from copper management, Codelco says it will not divert resources from other areas to lithium, according to the May 2023 *Bloomberg* article.[7] However, its temporary role as mediator in the public–private partnerships may be extended if the planned national lithium company is not established before the upcoming 2025 presidential election, "as some candidates could offer a different vision for the country's lithium," according to a report from the Eurasia consultancy, per *Reuters*.[9]

It is evident that Chile's ability to meet the minerals demand will take a dedicated effort from both private and public entities to harness the country's reserve of natural resources. The initiatives described above, if they come to fruition, should ideally help meet this demand.

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Bolstering domestic supply chains remains a focus of US policy

By Lisa McDonald

In a continuation from 2021, the U.S. government again spent 2022 advancing efforts to strengthen domestic supply chains, as described in the annual United States Geological Survey *Mineral Commodity Summaries* report.[1]

The *Mineral Commodity Summaries* report spotlights events, trends, and issues from last year in the nonfuel mineral industry. Every August, the *ACerS Bulletin* overviews some of the key facts covered in the report, including statistics on production, supply, and overall market for a selection of minerals and raw materials used in the ceramics and glass industry.

In 2022, consumption for many mineral commodities began to approach or exceed pre-pandemic (COVID-19) levels. In the United States, the estimated total value of nonfuel mineral production increased by 4% from 2021 to $98.2 billion. The total value of industrial minerals production increased as well, by 10% to $63.5 billion. Of this total, $31.4 billion came from construction aggregates production. Crushed stone accounted for the largest share of total U.S. nonfuel mineral production value in 2022 with 21%.

For the metals sector, several metals experienced reduced production due to reduced ore grades and weather-related issues. On the other hand, for the industrial minerals sector, increased construction and materials for energy and infrastructure projects as well as other manufacturing sectors led to increased production value.

The ongoing Russian invasion of Ukraine, which started in February 2022, disrupted mineral supply chains last year. For example, prior to the conflict, Ukraine was the leading source of titanium mineral concentrates supplying Russia's titanium metal industry. Following the invasion, major European and U.S. aerospace consumers of titanium have had to seek alternative supply sources.

In February 2022, the U.S. Geological Survey published the "2022 Final List of Critical Minerals."[2] This list, which revised the one published in 2018, increased the number of critical mineral commodities and mineral groups from 35 to 50. This change was due to the addition of nickel and zinc; listing out individual platinum-group metals and rare-earth elements; and the removal of helium, potash, rhenium, strontium, and uranium.

Even with these changes, the U.S.'s reliance on foreign sources for raw and processed mineral materials remained clear. In 2022, the U.S. was 100% net import reliant for 12 critical minerals and was more than 50% net import reliant for an additional 31 commodities. Recycling provided the only source of domestic supply for antimony, bismuth, chromium, germanium, tin, tungsten, and vanadium.

As in 2021, the U.S. government spent 2022 strengthening not only critical mineral supply chains but also domestic supply chains identified as areas of focus in Executive Order 14017.[3] On the Executive Branch side, President Joe Biden signed a presidential determination in March requiring the use of DPA title III authorities to strengthen the U.S. industrial base for large-capacity batteries,[4] specifically by increasing domestic mining and processing of critical battery materials. In October, Biden announced the launch of the "American Battery Materials Initiative,"[5] which will mobilize the entire government in securing a reliable and sustainable supply of critical minerals used for power, electricity, and electric vehicles.

Congress also took action on supply chains by passing two major pieces of legislation in August. The CHIPS and Science Act of 2022 provides $280 billion in funding over the next decade for domestic research, commercialization, and manufacturing of semiconductors as well as next-generation technology and workforce development.[6] The Inflation Reduction Act of 2022, which authorizes $391 billion in funding for climate change and domestic energy production, includes targeted tax incentives aimed at manufacturing U.S.-sourced materials and details key requirements around domestic sourcing.[7]

On the next two pages, a table summarizes some of the salient statistics and trends for a handful of mineral commodities that are of particular interest in the ceramic and glass industries.

Readers are encouraged to access the complete USGS report at https://doi.org/10.3133/mcs2023.

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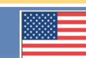
USGS MINERALS COMMODITY SUMMARIES

Leading producer highlights

	End use industries	Trend in global production	U.S. production	U.S. import/export	World reserves	Leading producer
ABRASIVES (fused aluminum oxide and silicon carbide)	Bonded and coated abrasive products	No change for fused aluminum oxide or silicon carbide	10,000 metric tons of fused aluminum oxide; 35,000 metric tons of silicon carbide	>75% net import reliance for fused aluminum oxide; 79% net import reliance for silicon carbide	Fused aluminum oxide: adequate Silicon carbide: more than adequate	Fused aluminum oxide and silicon carbide 
BAUXITE AND ALUMINA	Bauxite: refined for alumina or aluminum hydroxide, abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills	1% decrease for bauxite	Bauxite production information withheld	>75% net import reliance for bauxite	55 to 75 billion metric tons of bauxite	Bauxite 
	Alumina: used in production of aluminum, abrasives, ceramics, chemicals, refractories	0.7% increase for alumina	1.2 million metric tons of alumina	59% net import reliance for alumina		Alumina 
CEMENT	Construction	6.8% decrease for cement; 2.6% increase for clinker	95.0 million metric tons of cement; 80.0 million metric tons of clinker	21% net import reliance	Reserves of lime and stone (crushed) are very large and plentiful, respectively	
CLAYS	Tile, sanitaryware, absorbents, fillers and extenders, drilling mud, construction, paper, refractories	No change for bentonite; 1% decrease for Fuller's earth; 2.6% decrease for kaolin	26.0 million metric tons (50.0% common clay; 17.7% kaolin; 17.3% bentonite; 8.1% Fuller's earth; 6.9% other)	Net exporter	Extremely large	Bentonite  Kaolin  
FELDSPAR	Glass, tile, pottery	1.4% increase	420,000 metric tons (marketable production)	39% net import reliance	More than adequate	

	End use industries	Trend in global production	U.S. production	U.S. import/export	World reserves	Leading producer
GALLIUM	Integrated circuits, optoelectronic devices	21.1% increase	None (primary)	100% net import reliance	Gallium contained in world resources of bauxite is estimated to exceed 1 million tons, and a considerable quantity could be contained in world zinc resources. However, less than 10% of the gallium in bauxite and zinc resources is potentially recoverable.	
GRAPHITE (natural)	Batteries, brake linings, lubricants, powdered metals, refractory applications, steelmaking	13.1% increase	None	100% net import reliance	>800 million metric tons	
INDIUM	Flat-panel displays, alloys, solders, compounds, electrical components, semiconductors	3.4% decrease	None	100% net import reliance	Estimate unavailable	
IRON and STEEL	Construction, transportation (auto), machinery, equipment, energy	3.7% decrease for pig iron; 2.6% decrease for raw steel	21 million metric tons of pig iron; 82 million metric tons of steel	14% net import reliance	N/A	
KYANITE	Refractories, abrasives, ceramic products, foundry products	Cannot be calculated	100,000 metric tons	Net exporter	Significant	Kyanite  Andalusite 
LITHIUM	Batteries, ceramics, glass, lubricating greases	17.7% increase	Withheld	>25% net import reliance	Identified lithium resources total about 98 million tons	
MICA (scrap and flake)	Joint compound, oil-well-drilling additives, paint, roofing, rubber products	1.5% increase for scrap and flake	42,000 metric tons of sold and used; 67,000 metric tons of ground	24% net import reliance	More than adequate	
RARE EARTHS	Catalysts, ceramics, glass, metallurgical applications, alloys, polishing	3.3% increase	43,000 metric tons (mineral concentrates)	>95% net import reliance for compounds and metals; net exporter of mineral concentrates	Relatively abundant in earth's crust, but minable concentrations less common	
SODA ASH	Glass, chemicals, distributors, soap, detergents	3.3% increase	11 million metric tons	Net exporter	About 47 billion tons of identified natural soda ash resources; synthetic soda ash is practically inexhaustible but costlier to produce	
TITANIUM DIOXIDE (pigment)	Paints, plastic, paper, catalysts, ceramics, coated textiles, floor coverings, inks, roofing granules	N/A	1.1 million metric tons	Net exporter	Data not available	
YTTRIUM	Catalysts, ceramics, electronics, lasers, metallurgy, phosphors	~20% increase	N/A	100% net import reliance	Reserves are adequate, but worldwide issues may affect production	 
ZEOLITES (natural)	Animal feed, odor control, water purification, absorbent, fertilizer, pesticide	No change	86,000 metric tons	Net exporter	Estimate unavailable	

Ceramics Expo 2023: Driving the future of ceramics manufacturing

For the first time in its eight-year history, Ceramics Expo 2023 said farewell to its traditional home of Cleveland, Ohio, and moved to the Suburban Collection Showplace in Novi, Mich. The exposition, which took place May 1–3, welcomed more than 1,300 attendees and representatives from more than 220 exhibiting companies and supply chain partners.

Transportation and energy technologies were prevalent throughout this year's technical forums, which also included sessions on extreme applications and traditional and advanced manufacturing methods.

Transportation: From ICE vehicles to EVs

The opening session, moderated by ACerS director of technical content and communications Eileen De Guire, focused on the role of ceramics in the automotive industry.

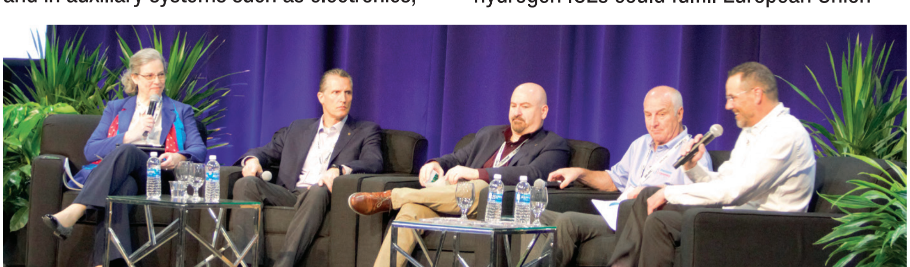
Keynote speaker Adam Schubring of Kyocera began the session by talking about the potential of this market to grow from $2.5 billion in 2022 to $5.1 billion by 2028. This growth is due not only to the growth of electric vehicles but also improvements to internal combustion engines (ICEs), mainly for emissions purposes.

Currently ceramics are used for parts such as cam rollers and valve disks within ICEs; in key moving parts such as clutches and brakes; and in auxiliary systems such as electronics, actuators, and exhaust components. New application areas include advanced sensing systems, such as LiDAR and compact radar for driver-assistance, along with thermoelectrics for climate control. Many of these technologies will persist with the transition to electric vehicles, along with the growth of other applications, such as inverters and LED lighting.

Understanding the timeline of the transition to electric vehicles is extremely important for the ceramics community. Most automotive manufacturers see the transition occurring in 2030–2035, with carbon emissions regulations as a strong driving force.

However, new technologies are needed to reduce adoption barriers, such as those for more efficient rapid charging and range extension. Several other challenges to adoption include getting more technical data on electric vehicles, such as battery lifetime (due to capacity changes); improving the environmental impacts of vehicle and electricity production; culture changes around vehicle ownership; and lack of students studying ceramic technologies.

Complicating these transition predictions are the development of ICEs that run on clean fuels, which minimize carbon emissions. Germany, for example is considering how hydrogen ICEs could fulfill European Union decarbonization goals. Plus, Toyota is introducing a hydrogen ICE vehicle.



Eileen De Guire of ACerS, far left, moderated the opening session of Ceramics Expo on the role of ceramics in the automotive industry. Panelists, from left, are Adam Schubring of Kyocera Automotive Components Division, Mark Wolf of Kyocera International, Geoff Randle of Precision Ceramics USA, and Casey Kurth of Qromis.

New applications and design paradigms

Ceramics in extreme environments (space travel, defense, and nuclear energy production) was a second application theme of the conference.

In the Day 2 keynote, Holly Shulman from Alfred University spoke of returning humans to the moon, possibly as early as 2027. Due to the extreme costs of moving materials from the Earth to space, production methods that take advantage of local raw materials on the moon and other planets are critical.

Shulman and others are working with materials that simulate the minerology (composition, shape, and size distribution) of regolith (crushed rock) on the surfaces of the moon and Mars. The two leading technologies for regolith utilization are microwave sintering and laser methods.

Interwoven with the applications areas were themes such as paradigm shifts in design and specification. For example, one presenter quipped that sometimes their customers request a part fabricated from "ceramic" to replace a part traditionally made from a superalloy metal. Additive manufacturing was also a recurring theme, often with questions around use in higher volume manufacturing and larger sized parts. Other themes included new techniques for nondestructive analysis and failure analysis of ceramics.

See more pictures from Ceramics Expo 2023 on the ACerS Flickr page at https://bit.ly/CEX23.

Next year, Ceramics Expo will return to the Suburban Collection Showplace in Novi, Mich., April 29–May 1, 2024. ■

Glass & Optical Materials Division meets in the Crescent City

The historic Hotel Monteleone in the French Quarter of New Orleans, La., provided the setting for this year's Glass & Optical Materials Division Annual Meeting on June 4–8, 2023.

Organized by Walter Kob (University of Montpellier) and Qiang Fu (Corning Inc.), the conference welcomed just over 300 people—including 73 students—from 21 countries. About 40% of the attendees were from outside the United States, with the largest representations coming from France, India, Japan, and the United Kingdom.

On Monday, the conference was planned to open with the Stookey Award lecture. Sadly, this year's recipient, Nicholas Borrelli, passed away in late January before he could accept the award. Instead, Borrelli's colleague, Matt Dejneka, accepted the award posthumously on his behalf and presented a tribute to Borrelli's prodigious, prolific career at the conference banquet.

On Tuesday, Stéphane Gin, senior scientist at the French Atomic Energies and Alternatives Energy Commission, presented the Morey Award lecture titled "Even glass corrodes in contact with water." His work shows there is not a universal corrosion mechanism in play but rather several mechanisms. Thus, the predictive model will need to be multifaceted to accommodate a spectrum of mechanisms across various parameter regimes.

GOMD chair Joe Ryan (right) presents a certificate of appreciation to program co-chair Walter Kob. Qiang Fu also served as program co-chair.

Qi Zhou from the University of California, Los Angeles, presented the Norbert J. Kreidl Award lecture on her Ph.D. work, which focused on understanding how basic structural features in silica glass control properties, similar to how DNA controls characteristics of living organisms.

Lisa Klein (Rutgers University) and Manoj Choudhary (Ohio State University and Owens-Corning [retired]) presented the Darshana and Arun Varshneya Frontiers of Glass Science and Technology Award lectures, respectively.

Klein, ever the consummate educator, used ice cream and chocolate chip cookies to describe complex principles of gel glass structure and glass transition behavior.

Choudhary's talk focused on industrial-scale glass melting technologies for reducing carbon footprint. The glass industry has been proactive in this area, for example, with electric boosting and all-electric melting, but challenges remain. He cited a February 2023 DOE report estimating that the U.S. need 47,300 gigawatt-miles of new power lines to meet growing demand, much of it coming from energy-intensive industries.

Two L. David Pye Lifetime Achievement Awards were presented at the banquet to Steve Feller of Coe College and (in absentia) to Carlo Pantano, retired from The Pennsylvania State University. Students were recognized as well for outstanding poster presentations.

In addition to the usual symposia and program tracks, GOMD chairs added a new session on STEM outreach, organized by Charmayne Lonergan (PNNL) and Katie Goetschius (Corning Inc.). This session looked at several programs designed to communicate the rewards of STEM careers to young students and to help them see how impactful careers in glass can be. Some of the programs that were highlighted included the Ceramic and Glass Industry Foundation's outreach activities; Olivia Graeve's ENLACE summer program, which links about 180 Mexican and U.S. high school and graduate students; and the Pacific Northwest National Laboratory's STEM Ambassador program.

There was also a poster session, publishing workshop, career panel discussion, glass corrosion short course, and ASTM meetings.

Images from GOMD 2023 are available on the ACerS Flickr site at https://bit.ly/GOMD2023. GOMD 2024 will take place next May 19–24 in Las Vegas, Nev. ■

Richard Brow, left, and Denise Krol enjoyed the Mardi Gras spirit of Sunday evening's welcome reception photo booth by dressing up as glass science royalty.

Structural clay experts convene in Austin, Texas, for networking, technical presentations, plant tours, and more

Attendees listen to instructions before the tour of Acme Brick's ENP and ELP plants.

More than 100 attendees converged in downtown Austin, Texas, on June 5–7 to take part in the combined meeting of the ACerS Structural Clay Products Division (SCPD), ACerS Southwest (SW) Section, and Clemson University's National Brick Research Center (NBRC).

Holly Rohrer, ACerS SCPD chair and president of Halbert Mill Co., says "The 2023 joint meeting was a success! We enjoyed hearing some excellent talks about our industry, as well as touring three great facilities. The social hours and banquet were also a great time to connect with others in our industry."

National Brick Research Center meeting

The meeting kicked off Tuesday morning with the NBRC Spring Executive Committee Meeting. NBRC director John Sanders and research associates Nate Huygen and Kathy Hill provided the members with updates at the center. Sanders reminded the committee of the upcoming Clemson Brick Forum, which takes place Oct. 2–3, 2023.

Technical session

On Tuesday afternoon, attendees heard from industry experts on a wide range of topics, including the use of drones for stockpile surveying, kiln car refractories, mental health issues in the workplace, and more.

Mat Tramel, ACerS SW Section chair and corporate laboratory manager at Acme Brick, says, "I thought that the speakers did a fantastic job, and it was a great mix of first time and established speakers that presented a wide variety of topics that I believe we all learned something new from."

Plant tours

On Wednesday, attendees toured three plants: Acme Brick's ENP and ELP plants (Elgin) and Red River Brick (Elgin). Attendees enjoyed a Texas BBQ lunch at Myers' Elgin Smokehouse before returning to the Omni Austin Hotel Downtown.

Networking and awards

Meeting attendees reconnected with old friends and built new relationships each evening at the SW Section hospitality reception on Monday, the Suppliers Mixer reception on Tuesday, and the awards banquet on Wednesday.

During the banquet, Tramel thanked everyone for attending and recognized the presenters, plant hosts, ACerS staff, and sponsors for helping make the meeting a success.

SCPD chair Holly Rohrer, left, presents Mike Rixner with the ACerS SCPD Best Paper award.

Several awards were given at the banquet. Mike Rixner of Brampton Brick received the 2022 SCPD Best Paper award for his presentation titled "The COVID Conundrum: Where do we go from here?" Tramel received the ACerS SW Section Past Chair award from SW Section secretary Fred McMann.

View more pictures from the SCPD–SW Section Annual Meeting on ACerS Flickr page at https://bit.ly/StructuralClay23. Next year's meeting is scheduled for June 17–19, 2024, in Oklahoma City, Okla. ■

SW Section secretary Fred McMann, right, presents Mat Tramel with the ACerS SW Section Past Chair award.

Acme Brick's Harland Dixson (center, white hat) guides a group through his plant.

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MATERIAL CHALLENGES IN ALTERNATIVE AND RENEWABLE ENERGY 2023 (MCARE 2023) COMBINED WITH Energy Harvesting Society meeting (EHS 2023)

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Calendar of events

August 2023

21–24 Materials Challenges in Alternative & Renewable Energy 2023 (MCARE 2023) combined with the 6th Annual Energy Harvesting Society Meeting (EHS 2023) – Hyatt Regency Bellevue, Bellevue, Wash.; https://ceramics.org/mcare-ehs-2023

27–31 ➨ 11th International Conference on High Temperature Ceramic Matrix Composites – Ramada Plaza Jeju Hotel, Jeju, Korea; https://www.ht-cmc11.org

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

30–31 EMC Ceramists Additive Manufacturing Forum (yCAM) 2023 – Leoben, Austria; https://euroceram.org/2023-ycam-forum-in-leoben

September 2023

25–28 ➨ 12th International Conference on Microwave Materials and Applications, Mainz, Germany; https://converia.uni-mainz.de/frontend/index.php?folder_id=786&page_id=

26–29 ➨ Unified International Technical Conference on Refractories (UNITECR) with 18th Biennial World-wide Congress on Refractories – Kap Europa, Frankfurt am Main, Germany; https://unitecr2023.org

October 2023

1–4 ACerS 125th Annual Meeting with Materials Science & Technology 2023 – Columbus Convention Center, Columbus, Ohio; https://matscitech.org/MST23

November 2023

5–10 ➨ 15th Pacific Rim Conference on Ceramic and Glass Technology – Shenzhen World Exhibition & Convention Center, Shenzhen, China; https://ceramics.org/event/15th-pacific-rim-conference-on-ceramic-and-glass-technology

6–9 ➨ Glass Week 2023 (Conference on Glass Problems and GMIC Symposium) – Columbus Convention Center, Columbus, Ohio; glassproblemsconference.org

January 2024

28–Feb 2 48th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2024) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla; https://ceramics.org/icacc2024

February 2024

13–16 Electronic Materials and Applications (EMA 2024): Basic Science and Electronic Materials Meeting – Denver, Colo.; https://ceramics.org/ema2024

April 2024

7–11 Pan American Ceramics Congress and Ferroelectrics Meeting of Americas – Hilton Panama, Panama City, Panama; https://ceramics.org/PACCFMAs-2024

22–24 Mineral Recycling Forum 2024 – Hilton Imperial Hotel, Dubrovnik, Croatia; http://imformed.com/get-imformed/forums/mineral-recycling-forum-2024

July 2024

14–18 International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; https://ceramics.org/ICC10

August 2024

18–22 ➨ 14th International Conference on Ceramic Materials and Components for Energy and Environmental Systems – Budapest Congress Center, Budapest, Hungary; https://akcongress.com/cmcee14

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Entries in **BLUE** denote ACerS events.

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

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deciphering the discipline

A regular column offering the student perspective of the next generation of ceramic and glass scientists, organized by the ACerS Presidents Council of Student Advisors.

Graciela Martinez
Guest columnist

Facing the lithium shortage

Due to properties such as high thermal and electrical conductivity, low density, and high electropositivity, lithium is a key material used in numerous industries, including the ceramics and glass industry, air conditioning, greases, dental prostheses, various alloys, and medicines. Electronics are the cornerstone of the lithium market, with about 59% of global lithium production being used to fabricate lithium-ion batteries (LIBs) for electric vehicles, phones, tablets and other devices.[1]

The demand for this element is expected to increase dramatically in the coming years as governments and countries fast track the transition to green energy. But there are some concerns related to the supply of this element (see "Lithium: The 21st century 'gold' rush" on page 22 of this issue). Considering these concerns, now is a good opportunity for science to make improvements in both the extraction and application of lithium.

From the extraction point of view, many scientists are investigating how to increase the purity of extracted lithium while minimizing the environmental impact of the extraction process. Traditional extraction techniques, such as pyrometallurgy or hydrometallurgy, are known for using excessive amounts of water, which become contaminated with base metals, such as cobalt.[1]

Lithium can also be obtained by recycling LIBs, which generally consists of a combination of pyrometallurgy, hydrometallurgy, and physical processes, among others. Obtaining lithium from LIBs has several drawbacks, however, such as the batteries not being immediately available for recycling, their transport and dismantling are expensive, and processing must be done carefully due to the high risk of explosion.[1]

Recently, other techniques like resynthesis or the use of microorganisms to extract base metals from spent LIBs have also been incorporated. These techniques, in addition to being environmentally friendly, are low cost. They still face some challenges to commercialization, including their long duration, low recovery, and the sensitivity of the microorganisms to temperature or pH.[1]

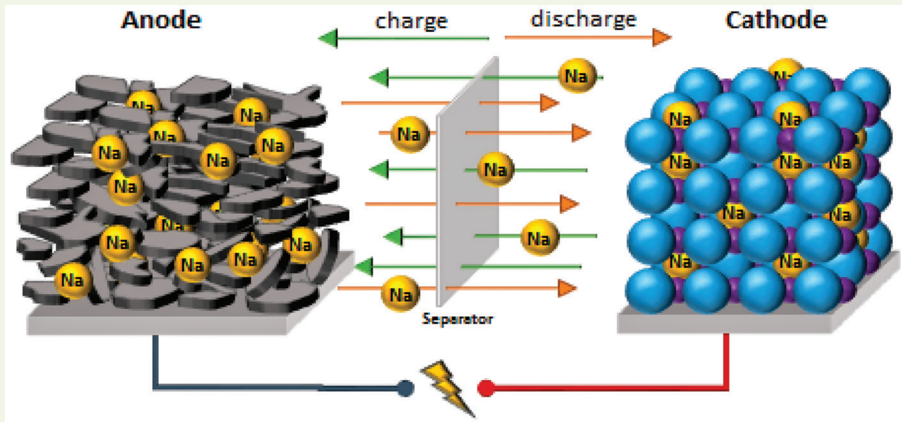

Illustration of a sodium-ion battery, one of the alternative battery compositions that may replace lithium.[3]

In terms of applications, scientists are investigating other materials that can replace lithium in batteries, such earth-abundant elements like sodium, potassium, magnesium, and aluminum. Studies have shown that batteries based on these elements can achieve similar performance to LIBs but at a lower cost.

There are challenges to commercializing these alternative battery chemistries. For example, although very efficient cathodes have been found for sodium-ion batteries, researchers are still searching for appropriate anode materials that will not form dendrites. On the other hand, magnesium and aluminum-based batteries do not suffer from dendrite formation, but it is difficult to find cathode materials to match them. The small size of these ions makes their insertion or extraction difficult, resulting in a very strong coulombic interaction with the host cathode material, which leads to high charge/discharge rates.[2]

The options discussed above represent just a few of the many ways to tackle the lithium shortage. Researchers will continually find aspects that they can improve and problems that they can study and solve.

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Graciela Martinez is a master's student at the Instituto Tecnológico de Saltillo in Mexico. Her graduate research involves developing advanced ceramics for solid oxide fuel cells and thermal barrier coatings in collaboration with the University of Castilla-La Mancha, Spain. In her free time, she enjoys playing video games and playing the drums.

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