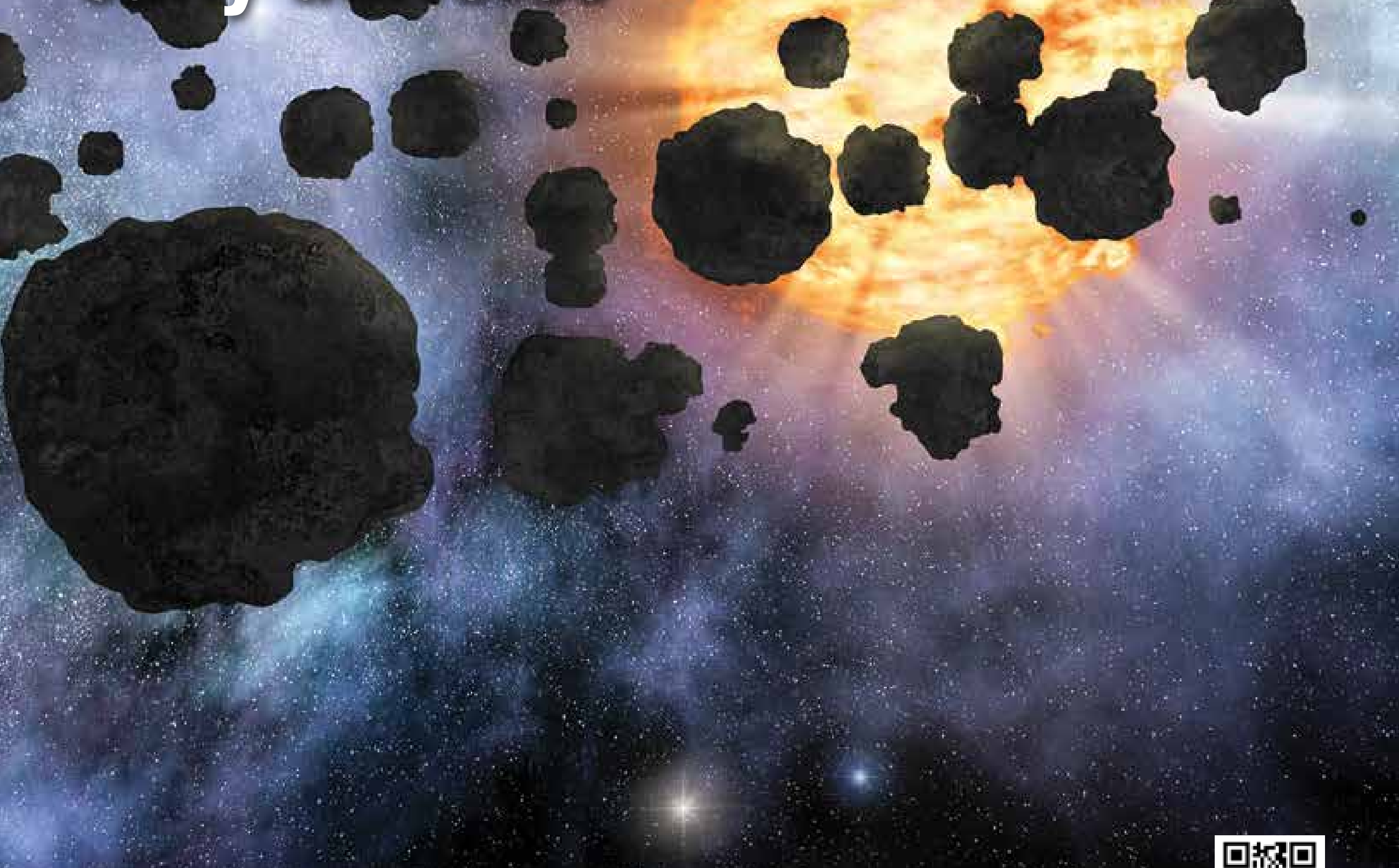
AMERICAN CERAMIC SOCIETY
bulletin
emerging ceramics & glass technology
AUGUST 2022

First glass:
Formation of silicate in the early universe



USGS Mineral Commodity Summaries 2022 | Refractory raw materials and sustainability

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Correction:

In the June/July 2022 issue of *Ceramic & Glass Manufacturing*, the given founding place of HarbisonWalker International was incorrect. This error has been corrected in the archival version of the issue.

AMERICAN CERAMIC SOCIETY
bulletin

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www.ceramics.org

August 2022 • Vol. 101 No.6

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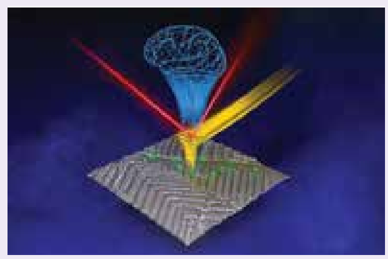
As seen on *Ceramic Tech Today*...


Credit: Adam Malin, Oak Ridge National Laboratory

The microscopist's dilemma: How to take advantage of an abundance of data

Storing data generated by sophisticated microscopy instruments is quite easy, but accessing, interpreting, and acting on the terabytes of data is challenging. Two recent papers offer interesting approaches to interacting with electron microscopes and the data they produce.

Read more at www.ceramics.org/microscopy

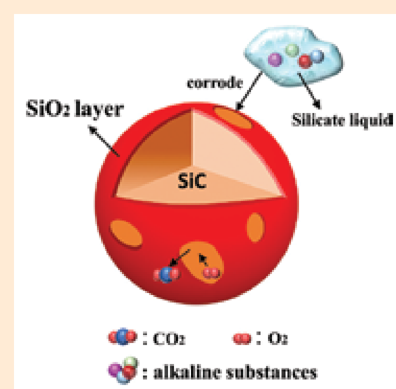
Also see our ACerS journals...

Waste-bearing foamed ceramic from granite scrap and red mud
By Y. Dong, C. Jiang, L. Zhang, et al.
International Journal of Applied Ceramic Technology

Magnesia-carbon refractories from recycled materials
By K. Moritz, S. Dudczig, H. G. Endres, et al.
International Journal of Ceramic Engineering & Science

Utilization of gold tailings for the construction of foamed ceramics used in external insulation buildings
By X. Duan, F. Meng, Z. Li, et al.
International Journal of Applied Ceramic Technology

Firing behavior of argillites from northern Tunisia as raw materials for ceramic applications
By Y. Chalouati, F. Mannai, A. Bennour, and E. Srasra
International Journal of Applied Ceramic Technology



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

Read more at www.ceramics.org/journals

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ACSBA7, Vol. 101, No. 6, pp 1– 48. All feature articles are covered in Current Contents.

news & trends

Fragility of the global submarine cable network and need for modernized regulation

While the fragility of land-based infrastructure systems such as power grids and roadways is gaining recognition, as evidenced by passage of the Bipartisan Infrastructure Law in the United States, there is another immensely important network that receives little attention—the global submarine cable system.

Submarine cables are fiber-optic cables that connect countries across the world via cables laid on the ocean floor. As of late 2021, there are about 436 submarine cables connecting all continents except Antarctica, and they carry about 95% of all global transnational communication data.

While well-populated coastal areas such as in the United States, the United Kingdom, and Japan have many submarine cable landing points, more remote nations are quite literally holding on to their connection by a single thread. Such is the case for the island nation of Tonga, which relies on a single submarine cable connecting it with Fiji, from where it connects to other international networks.

Tonga's tenuous connection to the global submarine cable network was made clear in January 2022 when the Hunga Tonga-Hunga Ha'apai volcano experienced a record-setting eruption that severed the Tonga cable. It took just over five weeks for the connection to be restored.

While this natural disaster severed a connection to just one nation, there are certain regions of the world where natural disasters often occur and where many submarine cables converge, such as around the Hawaiian Islands. In response, groups such as one at the University of Hawai'i are looking to enhance earthquake and tsunami early warning capabilities by integrating sensors into submarine cables.

However, natural disasters are not the greatest threat to submarine cables—humans are. "Despite the cables being clearly marked on maritime charts, about 70% of damage is caused accidentally by gear such as trawl nets, dredges, long lines, and fish aggregation devices," explains Karen Scott, University of Canterbury professor of international law, in an article on *The Conversation*.

According to Scott, part of the reason submarine cables are damaged so carelessly is because the international legal regime for protecting and managing submarine cables remains largely unchanged since 1884, when the Convention for the Protection of Submarine Telegraph Cables was adopted.

The result is that current rules dictate that outside of the territorial sea, the only state that can take action against a vessel that breaks a cable is the vessel's own flag state. Thus, "the state with an interest in the cable—through ownership or because the cable ultimately connects to its shore—is normally not able take action against a vessel damaging the cable," she writes.

"Given the potentially catastrophic impact on communications, the economy, and defense of losing major cables to accident or nefarious activity ... The rules, largely unchanged since 1884, need modernizing," she argues. ■

US mining companies lay plans for domestic rare earth processing facilities

With the growing concern of China tightening control of the global rare earth supply chain, countries are pouring resources into expanding rare earth extraction operations elsewhere, such as in North America and Australia.

However, mining rare earth ores is only the first step in securing the rare earths supply chain. For these ores to be useful, they must undergo refining processes to extract and purify the rare earth minerals so they can be used to manufacture various products. Currently, China controls nearly all the world's rare earth processing facilities. So, even when rare earth ores are mined elsewhere, they are shipped to China for separation and refining.

More companies are starting to lay plans for domestic processing facilities. In the April 2022 issue of *Ceramic & Glass Manufacturing*, content editor David Holthaus discusses how Las Vegas-based MP Materials has plans to restore the capacity to separate and process rare earths at the California-based Mountain Pass facility sometime late this year. The company also plans to build a rare earth metal, alloy, and magnet manufacturing facility in Fort Worth, Texas.


Credit: MP Materials

An illustration of the rare earth metal, alloy, and magnet manufacturing facility that MP Materials plans to build in Fort Worth, Texas.

In June 2022, Texas-based USA Rare Earth made the significant announcement that it will establish the first fully integrated U.S.-based rare earth metal and sintered neodymium magnet manufacturing facility in Stillwater, Oklahoma.

USA Rare Earth controls and operates the Round Top Heavy Rare Earth, Lithium, and Critical Minerals Project in Hudspeth County, Texas. In April 2020, the company acquired the only sintered neodymium magnet manufacturing equipment in the western hemisphere from Hitachi Metals America Ltd. They stored this equipment while deciding where to locate the new magnet operation—which will be the newly announced $100 million Stillwater plant. It is expected to start production in 2023.

In addition to the new facility, USA Rare Earth is collaborating with Texas Mineral Resources Corp. on a pilot plant in Wheat Ridge, Colorado, to improve separation capabilities. The plant first opened in June 2020, and the company provided an update on progress in August 2021. ■

'Sand battery' keeps Finnish town warm during the dark, cold winters

As demands on our energy infrastructure increase in response to climate change, adapting to this new normal not only requires updating our existing systems but also designing new ways of storing and transmitting energy that can better withstand extreme environments. Fortunately, researchers around the world are hard at work advancing novel solutions.

A new sand-based heat storage system by Finnish startup Polar Night Energy is an example of these efforts. Tampere-based Polar Night Energy is the brainchild of engineers Tommi Eronen and Markku Ylönen. Their company grew from the knowledge that relying on power stations during cold Finland winters can be extremely expensive and emission intensive.

Their solution for providing stable and affordable thermal energy is a "sand battery." In this system, electricity generated from solar and wind power passes through an array of electric resistive heating elements, heating the air around it. This hot air circulates through a network of pipes inside an insulated sand-filled steel tank, which warms the sand up to about 500°C (932°F). The air then flows back out of the tank into a heat exchanger, where it heats water that is then circulated through building heating systems.

The first commercial installation of a sand-based heat storage system by Finnish startup Polar Night Energy.

Credit: MP Materials

When the sun sets, the sand's stored heat is gradually released back into the circulating airflow, keeping the air hot enough to maintain the water at a steady temperature. In this way, sand enables renewable energy to keep people warm, even during the darkest and coldest Finnish nights.

Eronen and Ylönen chose sand as the heat storage medium due to its superior heat storage capacity compared to existing water-based heat storage systems. "There is only so much heat you can add to water before it becomes steam. Steam can efficiently distribute heat, but it is not really cost-effective for large-scale storage," Eronen says in an interview.

In contrast, the sand in their system can hold on to the heat for several months, which is perfect for when the sun does not rise above the horizon in Lapland, Finland's northernmost region.

In July 2022, BBC reported that Eronen and Ylönen completed the first commercial installation of their sand battery in the town of Kankaanpää. It was installed at the Vatajankoski power plant, which runs the district heating system for the area. ■

Corporate Partner news

Nabertherm GmbH: Celebrating 100 years of Conrad Naber

Conrad Naber, founder of furnace construction company Nabertherm GmbH, was born in Bremen on July 1, 1922. He died on Jan. 29, 2018, at the age of 95. Nabertherm commemorated what would have been his 100th birthday in a very sporty way with the "Conrad Naber Cup" soccer tournament. On a larger scale, the company founder will be commemorated again in September.

"Conrad Naber was a goal-oriented and ambitious, always very open and open-minded entrepreneur, who always had an ear for his employees," says Timm Grotheer, the current managing director of Nabertherm GmbH. ■

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

Women in glass—beyond the glass ceiling

By Christine Heckle, Carol Jantzen, Denise M. Krol, and Kathleen A. Richardson

University of Central Florida post-docs at a Women in STEM Day in 2015, supporting the recruitment of middle school students into glass science and engineering.

Credit: Kathleen Richardson

The International Year of Glass (IYOG) provides an opportunity to evaluate the progress made on diversifying the face of glass across the world.

The following multigenerational perspective of leaders within the U.S. glass community offers a benchmark on how far we have come and how far we have yet to go in the inclusion of women and minorities in the global glass community.

Industry

Corning

• Mary Purcell Roche: Initially turned away because "women were disruptive in the lab," Roche became the first woman scientist at Corning Glass Works in 1942 with a M.S. in biochemistry.

• Ellen Lunn Mochel: In 1955, Mochel became the first woman with a Ph.D. to work at Corning after her husband argued that she be hired as a requirement for his own employment. Mochel investigated the reaction of sulfur dioxide with glass, which led her to work on Project Muscle, which advanced the concept of ion exchange to strengthen glass, which became a key building block for the future Gorilla Glass.

• Linda Pinckney: In 2002, Pinckney was named Corning's first woman research fellow.

• Lina Echeverria: In 2008, Echeverria was named the first woman vice president in the Science & Technology Division.

Bell Labs

• Suzanne Nagel: A 1972 Ph.D. graduate of the University of Illinois, Nagel served as a leader in Bell Labs' quest for low-loss optical fiber technology. In 1992, she was the first woman be appointed a Bell Labs Fellow, the highest technical recognition at Bell Labs. Nagel used her visibility to create mentoring opportunities for other women. In her honor, the 2018 Optical Fiber Communication Conference and Exhibition introduced a new networking space, the Suzanne R. Nagel lounge, focused on improving gender equity at the conference and the field of optical communications.

• Eva M. Vogel: Vogel was hired as one of very few technical women in 1970 in the materials research department. After she joined Bellcore (now iconectiv) in 1984, she became a leading scientist on nonlinear optical properties of glasses. Vogel was keenly aware of the difficulties facing women in glass science and was a mentor and adviser to young women scientists. She was also the first woman chair of the ACerS Electronics Division (1993–1994).

• Martina Sabourin: Sabourin was one of the first Asian women to support the Bell Labs team in their initial activities in prototyping and transitioning solutions in the flat panel display area in the early 1990s. Following her departure from Bell Labs in the mid-90s, Sabourin led quality and compliance activities at Owens Corning, Tyco Communications, and her current position at ThorLabs.

Academia

The Institute of Silicate Chemistry (St. Petersburg, Russia), Sheffield University (U.K.), and Alfred University (U.S) were the first universities to offer glass-related degree options. Alfred University graduated its first woman with a bachelor's in glass technology, Sylvia Gailar, in 1937. Gailar went on to become one of the first women to join the U.S. Army, designing lenses for military systems.

These institutions and others had some of the first women faculty teaching glass science and leading research efforts, including Natalia Vedishcheva (Inst. Silicate Chemistry), Doris Ehrt (Friedrich Schiller University, Germany), Angela Seddon (Sheffield University, now at University of Nottingham), and Alexis Clare (Alfred University). These women served as mentors to many of the women featured in the special "Women in Glass" issue of the *International Journal of Applied Glass Science*,[1] including Doris Möncke, Liping Huang, Delia Bauer, Alicia Durán, Kathleen Richardson, Heike Ebendorff-Heidepriem, Annie Pradel, Ana Candida Rodriguez, and Laeticia Petit.

The future of glass and STEM

Educators are recognizing the need to not only attract diversity into STEM-related academic programs, but to retain and mentor them into lifelong careers. Though slow, these efforts are starting to bear fruit, as evidenced by the gender diversity now seen at conferences and meetings.

References

[1]"Special Issue: Women in Glass," *International Journal of Applied Glass Science* 11 (3). Eds. Alicia Durán, Lili Hu, Kathleen A. Richardson, (2020). ■

Adapted from "Women in Glass–beyond the glass ceiling," by Heckle et. al, in National Day of Glass, by A.K. Varshneya, M.K. Choudhary, and L.D. Pye, eds. The American Ceramic Society (2022)

Global electric vehicle battery reuse and recycling market

By BCC Publishing Staff

The global electric vehicle battery reuse and recycling market was valued at $936 million in 2019 and is estimated to grow at a compound annual growth rate (CAGR) of 43.1% to reach $8.4 billion in 2026.

Over the last decade, the cost of electric vehicle batteries decreased significantly because of technology improvements and mass production. In 2010, the cost of an electric vehicle battery was approximately $1,100 per kWh. By 2020, the price had dropped to roughly $156 per kWh. By 2030, battery prices for electric vehicles are predicted to decline to roughly $60 per kWh.

Lithium-ion and lithium polymer batteries are the most prevalent battery types in modern electric vehicles due to their high energy density in relation to their weight. Nickel-cadmium, nickel-metal hydride, lead-acid (and, less frequently, zinc-air and sodium nickel chloride) batteries are used as well.

Batteries retired from electric vehicle applications may be reused (i.e., repaired and used in other electric vehicles) or repurposed (i.e., tested, frequently repacked, and then used in less demanding applications such as stationary energy storage).

For battery reuse, availability is mostly determined by the rate of electric vehicle retirement, with the understanding that retirement can occur due to aging or an accident, in which case safety standards are critical and not all batteries will be allowed for reuse. Direct reuse is less expensive; however, it limits adaptation choices owing to stacking issues. Module disassembly enables a more versatile solution capable of transitioning from tiny to large systems.

There are two main methods of battery recycling: pyrometallurgy/smelting and hydrometallurgy, which can be employed independently or in conjunction with one another.

- **The pyrometallurgy process** involves melting lithium-ion and nickel-metal hydride batteries with the primary goal of recovering high-value metals such as cobalt, copper, nickel, and iron. The melt alloys are fed into a hydrometallurgical process, where battery metals are separated by chemical attack by acids and precipitation into salts. This process removes lithium, aluminum, and manganese from the slag stream.
- **The hydrometallurgy process** incinerates lithium batteries at 1,000°C, evaporating the organic solvents, lithium, and fluorides contained in the batteries. The remaining metals are separated using hydrometallurgy with the purpose of primarily recovering cobalt.

Table 1. Global market for electric vehicle battery reuse and recycling, by region, through 2026 ($ millions)

Region	2019	2020	2021	2026	CAGR % (2021–2026)
North America	202.9	245.3	307.4	1,904.0	44.0
Europe	299.5	370.8	475.4	3,260.4	47.0
Asia-Pacific	355.7	417.5	507.7	2,670.7	39.4
South America	48.9	58.4	72.4	412.8	41.6
Middle East and Africa	29.0	33.3	39.5	176.9	35.0
Total	**936.0**	**1,125.4**	**1,402.4**	**8,424.8**	**43.1**

- **Other procedures** recover not only the high-value-added metals or key raw materials from batteries but also the battery components in the form of salts. A mechanical recycling process in which the electrolyte is extracted separately and the battery cells are broken down to concentrate the metals is an example of this type of recycling.

Globally, the production and sales of new vehicles ceased during the preliminary outbreak of COVID-19, and this harmed the whole ecosystem. However, following the lockdowns, demand for electric vehicles increased dramatically as governments around the world increasingly pushed for the use of low-emission vehicles. Numerous countries also boosted the number of electric vehicles charging stations and hydrogen filling stations throughout their states.

Europe (including the EU and U.K.) leads the market for electric vehicle sales, with a combined electric market share of 14% in the first six months of 2021. Many of the electric vehicles sold in Europe are plug-in hybrids, whereas 80% of electric vehicles sold outside of Europe are pure electric.

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.

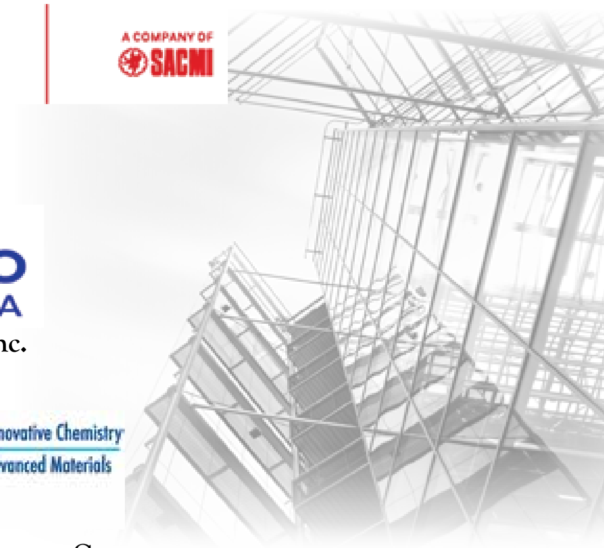
Resource

BCC Publishing Staff, "Global electric vehicle battery reuse and recycling market" BCC Research Report FCB058A, February 2022. www.bccresearch.com. ■

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners.



Laeis GmbH

Showa Denka America, Inc.

Pacific Industrial Development Corp.

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

ACerS welcomes new Arizona Section

ACerS is pleased to announce that the Board of Directors approved a petition to establish the Arizona Section of The American Ceramic Society. As a local source of ceramic and glass industry education, information, and interaction, ACerS Sections bring the Society's vast resources directly to members.

Officers of the new section are

Chair: **Majid Minary-Jolandan**, Arizona State University

Treasurer: **Sharhiar Anwar**, Arizona State University

Secretary: **Saurabh Waghmare,** Heraeus Conamic

Welcome to the newest ACerS Section! ■

Eastern Washington Section webinar: 'Why is now a good time to be a student?'

The ACerS Eastern Washington Section, in collaboration with Pacific Northwest National Laboratory and Washington State University, hosted a student webinar on June 1, 2022.

Titled "Why is now a good time to be a student?", the webinar featured talks by five presenters from Washington State, PNNL, and ACerS who shared their experience and discussed several comprehensive, career-building undergraduate and graduate internship opportunities. The presentation can be viewed at https://www.youtube.com/watch?v=FfUJlCc2-2w. ■

The Italian Ceramic Society and ACerS Italy Chapter host 'Thousand lives of glass' symposium

More than 60 participants attended the "Thousand lives of glass" symposium on May 20, 2022, in Venice, Italy.

The Best Poster Award Winners were

- **Angelica Luceri**, 1st place
- **Alessandro De Zanet**, 2nd place
- **Elisa Zanchi**, 3rd place ■

Volunteer spotlight

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

Chen

Gang Chen received his Ph.D. in materials science and engineering from Lehigh University. Prior to joining Ohio University, he was a postdoctoral fellow at Argonne National Laboratory.

He currently is associate professor in the Department of Physics and Astronomy at Ohio University. Chen's research group focuses on advanced X-ray characterization of disordered materials including, but not limited to, nanostructured glasses and amorphous semiconductors.

Chen has been a member of ACerS Glass & Optical Materials Division for more than two decades, and he is currently chair of the Division. Chen is also an outreach ambassador for the 2022 International Year of Glass.

We extend our deep appreciation to Chen for his service to our Society! ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

FOR MORE INFORMATION:

ceramics.org

ACerS Germany Chapter teams up to organize International Materials Slam 2022

By Rishabh Kundu and Manuel Best

The International Materials Slam 2022 (IMS 2022) was a three-day, virtual, student-led outreach event designed to encourage, motivate, and facilitate networking among young materials science enthusiasts from across the globe. Conceived by the Special Projects Committee of ACerS Manufacturing Division, it was coorganized by ACerS Germany Chapter and the German Materials Society and welcomed more than 100 participants from four continents.

Credit: ACerS Germany Chapter

An energetic presenter of a creative slide during PowerPoint Karaoke on Day 2 of IMS 22.

Day 1, held on May 28, featured a talk by Sanjay Mathur, department chair and director of the Institute of Inorganic Chemistry at the University of Cologne, Germany. His talk, "Between borders: Practicing science at cultural and disciplinary interfaces," drew insights from his journey from a Ph.D. student in India to a professor in Germany and how embracing change and keeping an open mind helped him learn from both experiences. An engaging discussion, facilitated by an active audience, followed the talk.

Day 2, held on June 4, featured two events: Science Slam highlighting work from young materials science students and researchers, and PowerPoint Karaoke provided an opportunity for students to improve their impromptu speaking skills. For Science Slam, participants sent in a prerecorded video of up to five minutes about their work or interests relevant to materials science. PowerPoint Karaoke asked participants to impromptu present a single slide prepared by someone else in 1–2 minutes.

There were cash prizes for each event, including for both those who submitted slides and those who presented them during PowerPoint Karaoke. ACerS student members Carina Rindtorff Pérez and Ruth Adam assisted the organizers with executing the Day 2 events.

Day 3, held on June 11, featured a talk by Gerhard Schneider, director of the Materials Research Institute at Aalen University, Germany. His talk, "High-throughput search for green alternative materials," emphasized the need for young researchers to explore novel methodologies and shorten the time of technology readiness level advancement. He also stressed the need to firmly couple sustainability aspects with new materials development, giving a few examples from his own research. His talk was followed by interesting questions by the audience.

The successful event concluded with the organizers thanking everyone who participated. ■

Science Slam and PowerPoint Karaoke winners

PowerPoint Karaoke slide designers
1st place: Siddhartha Nanda
2nd place: Lisa Nguyen
3rd place: Seulgi Ji, Vidushi Galwadu Arachchige, Marie Neumann, Nabojit Kar (shared)

PowerPoint Karaoke presenter
1st place: Deepsikha Brahma
2nd place: Pentakota Uday Kumar
3rd place: Marie Neumann

Science Slam
1st place: Nils Winkelmann
2nd place: Siddhartha Nanda
3rd place: Nabojit Kar, Linus Erhard, and Bohnni Shikha Biswas (shared)

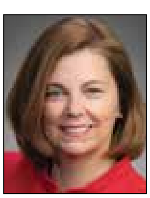
IN MEMORIAM

Vernon Berdick
You Song Kim
Harry Mills
Andy Nieto

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

Names in the news

Aldo R. Boccaccini, FACerS, professor and head of the Institute of Biomaterials at the University of Erlangen-Nuremberg, Germany, was conferred the degree of Honorary Doctor of Philosophy at Åbo Akademi University, Turku, Finland.



Goski

Dana Goski, FACerS, vice-president of research at Allied Mineral Products, was elected as an Academician by the World Academy of Ceramics.

Laurencin

Cato Laurencin, FACerS, Albert and Wilda Van Dusen Distinguished Endowed Professor of Orthopedic Surgery at the University of Connecticut School of Medicine, was elected to the European Academy of Sciences.

Randall

Clive Randall, FACerS, distinguished professor of materials science and engineering and director of the Materials Research Institute at The Pennsylvania State University, was named 2021 Fellow of the National Academy of Inventors. ■

IJCES to be listed on Scopus

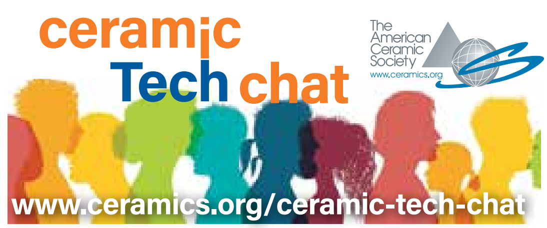
ACerS' open-access *International Journal of Ceramic Engineering & Science* was accepted for listing by the Scopus Content Selection & Advisory Board.

This listing is a major milestone achievement for ACerS's Gold Open Access journal. Listing on Scopus enables authors in many countries, particularly emerging economies, to receive career credit for articles published in *IJCES*. The journal expects a substantial increase in submissions as a result.

This achievement recognizes the hard work of *IJCES* editor-in-chief Ricardo Castro and his expert editorial team to attract and publish high quality articles pertinent to our community. We look forward to the journal continuing its mission and attaining further recognition for years to come. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

Ceramic Tech Chat: Mathieu Hubert



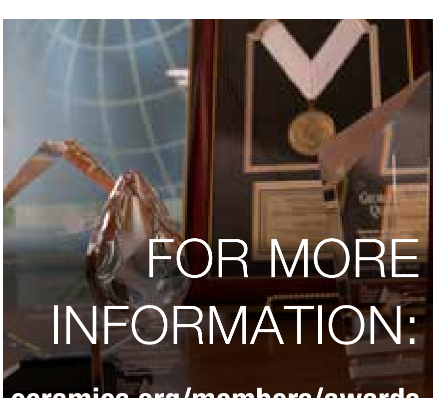
Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the second Wednesday of each month.

In the June episode of Ceramic Tech Chat, Mathieu Hubert, glass development scientist and development program manager at Corning, shares how he came to a career in researching advanced glasses, the challenges in educating more people about these materials, and how he helps support the next generation of glass scientists. Check out a preview from his episode, which features Hubert discussing the importance of diversity in glass development.

"There's a lot of challenges everywhere and everything needs to happen properly. We need a lot of people with a lot of different backgrounds and a lot of different views and input in the process to make it successful. It's not a one-man process where somebody comes in and says, 'Oh yeah, I'm going to make you a great glass,' and figure everything out by themselves. In some of my talks I use the reference that it takes a village to raise a child. Same thing for glass. It takes a lot of people with a lot of backgrounds and a lot of experience to make a good glass."

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

AWARDS AND DEADLINES



Society Awards	Nomination Deadline	Contacts
Darshana and Arun Varshneya Frontiers of Glass Lectures	Sept. 1	Erica Zimmerman ezimmerman@ceramics.org
Society Fellows	Jan. 15	Erica Zimmerman ezimmerman@ceramics.org
Samuel Geijsbeek PACRIM International	Jan. 15	Erica Zimmerman ezimmerman@ceramics.org

Attend your Division business meeting at MS&T22

Six of ACerS Divisions will hold executive and general business meetings at ACerS Annual Meeting in conjunction with MS&T22 in Pittsburgh, Pa. General business meetings will be held Monday or Tuesday in the David L. Lawrence Convention Center. Plan to attend to get the latest updates and to share your ideas with Division officers.

Monday, Oct. 10

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

Tuesday, Oct. 11

Basic Science Division
Noon–1 p.m.
Art, Archaeology, & Conservation Science Division
TBD ■

	Description
	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.
	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.
	Recognizes individuals who are members of the Pacific Rim Conference (PACRIM) societies, for their contributions in the field of ceramics and glass technology that have resulted in significant industrial and/or academic impact, international advocacy, and visibility of the field.

more AWARDS AND DEADLINES

Do you qualify for Emeritus membership?

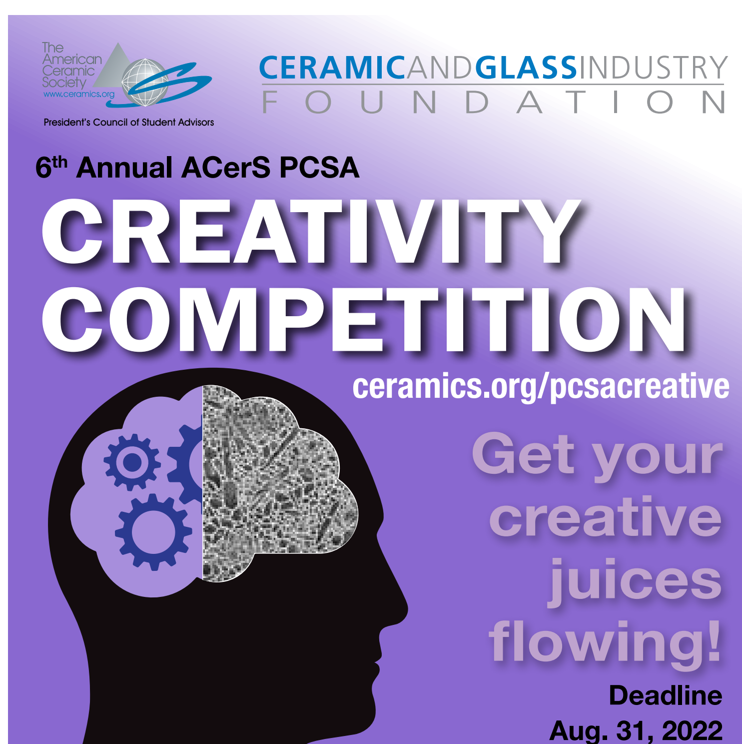
If you will be 65 years old or older by Dec. 31, 2022, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Erica Zimmerman at ezimmerman@ceramics.org. ■

Division	Award	Nomination Deadline	Contacts	Description
BSD	Graduate Excellence in Materials Science (GEMS)	Aug. 12	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. 30	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

6th annual PCSA Creativity Competition

Submissions are now being accepted for the 6th annual PCSA Creativity Competition. The deadline for submissions is **Aug. 31, 2022**. To find out more and apply, visit ceramics.org/pcsacreative. ■



FOR MORE INFORMATION:

www.ceramics.org/students

#YoungProPerks: Free one-year Associate membership

Are you transitioning from the hallowed halls to the corporate jungle? If you have recently graduated and are on a job search—or have already started on your professional path—let ACerS provide you with a graduation gift of a free one-year Associate membership. Sign up for your membership at www.ceramics.org/associate. ■

ACerS GGRN for young ceramic and glass researchers

Put yourself on the path toward post-graduate success with ACerS Global Graduate Researcher Network. ACerS GGRN addresses the professional and career development needs of graduate-level research students who have a primary interest in ceramic and glass materials.

The American Ceramic Society
www.ceramics.org
Global Graduate Researcher Network (GGRN)

GGRN aims to help graduate students

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

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. ■

more STUDENTS AND OUTREACH

Student competitions at MS&T22

Undergraduate Student Poster Contest

Award amounts: 1^{st} place: $250; 2^{nd} place: $150; 3^{rd} place: $100.

All undergraduate students are eligible. To enter, submit an abstract of no more than 150 words by **Sept. 9, 2022**, to the symposium titled “2022 Undergraduate Student Poster Contest.” Learn more and enter at https://bit.ly/3OKZnad.

Undergraduate Student Speaking Contest

Award amounts: 1^{st} place: $500; 2^{nd} place: $250; 3^{rd} place: $150; 4^{th} place: $100

Undergraduate speaking contestants must be reported to Yolanda Natividad at ynatividad@ceramics.org by **Sept. 16, 2022**. Please refer to the website for current rules and enter at https://bit.ly/3OKZnad.

Graduate Student Poster Contest

Award amounts: 1^{st} place: $250; 2^{nd} place: $150; 3^{rd} place: $100.

Only those graduate students who have an accepted poster abstract at MS&T are eligible to enter the poster contest. Graduate Student Poster contestants must be reported to Yolanda Natividad at ynatividad@ceramics.org by **Sept. 9, 2022**. Learn more and enter at https://bit.ly/3OKZnad.

Graduate Excellence in Materials Science (GEMS) Awards

Award amounts: Each finalist receives a cash honorarium of $100 and a certificate from ACerS.

Open to graduate students making oral presentations at any symposium at MS&T22. In addition to their MS&T abstract submission, students must also submit a nomination packet to the chair of the GEMS Award selection committee, John Blendell at Blendell@Purdue.edu by **Aug. 12, 2022**. Learn more and enter at www.ceramics.org/gems. ■

ACERS BOOKSHELF

CHECK OUT THESE TWO NEW TITLES FROM ACERS/WILEY

Looking for a new book to read this year? Two new titles by ACerS-Wiley are available on www.wiley.com/ceramics.

Bioactive Glasses and Glass-Ceramics: Fundamentals and Applications, edited by Francesco Baino and Saeid Kargozar

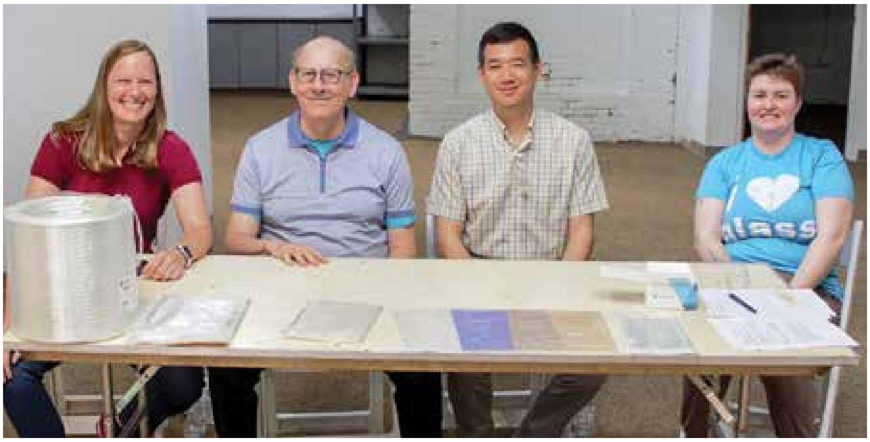
This book presents topics on the functional properties, processing, and applications of bioactive glasses and glass-ceramics.

82^{nd} Conference on Glass Problems, Volume 270, edited by S. K. Sundaram

This latest issue in the industry-leading Ceramic Transactions series delivers the newest research, data, and information relevant to glass manufacturing. ■

Hot glass outreach event hosted at GOMD in Baltimore

Students watch with anticipation as glassblower Anthony Corradetti wields a flame to sculpt glowing, hot glass in his studio. By his side, materials scientist Joe Ryan narrates his actions for a group of high school students to highlight the science behind the art.



Panelists answer student questions about materials science careers. From left to right: Michelle Korwin-Edson, Howard Cohen, Gang Chen, and Brittney Hauke.

For many of these young Baltimore residents, Corradetti's demonstration served as their first introduction into the world of materials science.

"The goal of the event was to introduce the high school students to the art and science of glass and give examples of what types of careers are possible and how to pursue them," says Irene M. Peterson of Corning Research and Development.

Peterson led the planning team for the Baltimore high school outreach event, which took place on May 27, 2022, the day after the Glass & Optical Materials Division annual meeting finished. Peterson serves as the executive committee vice chair of GOMD, and she used her connections in the Division to recruit graduate student volunteers from ACerS President's Council of Student Advisors. Owens-Corning and Corning Research and Development sponsored the event along with GOMD.

Glass artist Anthony Corradetti torches a bowl with help from his assistant during the outreach event.

Three Baltimore schools—Western High School, Baltimore Design School, and Baltimore City College—participated in the event at Corradetti Glassblowing Studio and Gallery. In total, 90 students and four teachers attended Corradetti's glass blowing demonstrations. Following the demonstrations, students engaged in a lively career panel aimed to inspire the high schoolers and show them that a career in the materials science industry is not out of their reach.

"The most rewarding part was to see the wonder and joy on the faces of the students at the glassblowing demonstration and hear them ask questions so eagerly during the career panel," Peterson says.

Gang Chen, an associate professor in the physics and astronomy department at Ohio University, also helped on the planning committee and served as one of the career panelists.

"High school students will make an important decision when they go to college: What should I study as an undergraduate student?" Chen says. "It is very important to introduce them to a field related to science, technology, engineering, and math and let them think about if this field is something they are interested in."

Feedback from students on the event was also positive. "I loved the science behind [the glass blowing] and I'm interested in glass making," says Brianna B., a student at Western High School. "The glass art within the room was beautiful." ■

Two high school students observe glass artists working in the studio.

New method shows promise repairing localized damage in thermal barrier coatings

In a recent open-access paper, researchers from Forschungszentrum Jülich (FZJ) in Germany proposed a new method for repairing localized damage in thermal barrier coatings (TBCs).

TBCs are multilayer coatings applied to aircraft turbine blades to protect them from the high-temperature, corrosive environment of the engine. TBCs typically consist of four layers: the metal substrate, metallic bond coat, thermally grown oxide, and ceramic topcoat.

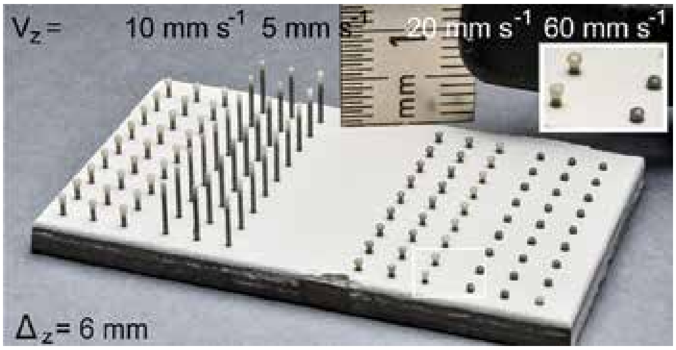
Today, the ceramic topcoat in many state-of-the-art TBCs features a columnar rather than smooth microstructure. Such a structure imparts a certain pseudo-plasticity to the coating, which translates into better tolerance to spalling, strain, and thermal shock.

As with any material, usage leads to wear of TBCs, and current methods for repairing this multilayer coating face limitations. For example, the inability to perform complex spot repairs can lead to inadvertent blockage of the cooling holes, which help prevent turbine blades from overheating. To avoid blockage, it can become necessary to perform a full coat removal and reapplication to address localized damage. Thus, there is a great need to develop methods for performing intricate point reconstruction without clogging the cooling system.

The new repair method developed by the FZJ researchers is a laser-cladding-based additive manufacturing technique named Clad2Z. Laser cladding is a surface modification technique that conventionally is used to deposit metal layers. It involves feeding a stream of powder or a wire into a melt pool that is generated by a laser beam as it scans across the target surface, depositing a coating of the chosen material.

Airplane manufacturers have used laser cladding with metal powder to repair turbine blades for several decades. Trying to deposit a smooth, homogeneous ceramic coating on the metal blade using this technique, however, almost inevitably leads to crack formation due to high residual stress from solidification shrinkage and thermal expansion coefficient mismatch between the coating and blade.

However, producing coating with microcolumn morphologies, which many state-of-the-art TBC ceramic topcoats consist of, could lead to "the formation of cracks due to thermomechanical stresses can in principle be suppressed—even for completely dense columns, if they have a sufficiently small cross section," the FZJ researchers write.



Laser cladded yttria-stabilized zirconia microcolumns processed at different vertical robot velocities with 20-W laser power.

For their study, they used laser cladding to produce a coating made from yttria-stabilized zirconia (YSZ), which is one of the most widely used materials for TBCs. Their process involves using an argon gas jet to blow a fine YSZ powder into a laser-generated melt pool on Inconel 738, a nickel-based superalloy commonly used as a blade material. They slowly moved the laser beam and powder feed upward about five millimeters per second, allowing them to grow the YSZ microcolumn in a precisely controlled manner.

Repeated hundreds of times, they created an entire forest of closely spaced microcolumns, each less than half a millimeter to six millimeters long. Because the columns were created individually, the process did not block any of the cooling holes.

Thermal cycling performance tests showed the Clad2Z TBCs outperformed TBCs created through suspension plasma spraying, an evolving technique for manufacturing columnar TBCs. The Clad2Z TBCs also performed well within the range of commercial TBCs deposited via electron beam physical vapor deposition, which is the established state-of-the-art method for manufacturing columnar TBCs.

"Once further development and certification have taken place, components with conventional thermal barrier coatings could be repaired [using this new method]," says Christoph Vorkötter, first author and previous FZJ postdoctoral researcher, in an FZJ press release (translated).

The researchers applied for a patent for their new method and are looking for partners in industry to help advance development.

The open-access paper, published in *Advanced Materials Technologies*, is "Additive manufacturing of columnar thermal barrier coatings by laser cladding of ceramic feedstock" (DOI: 10.1002/admt.202200098).

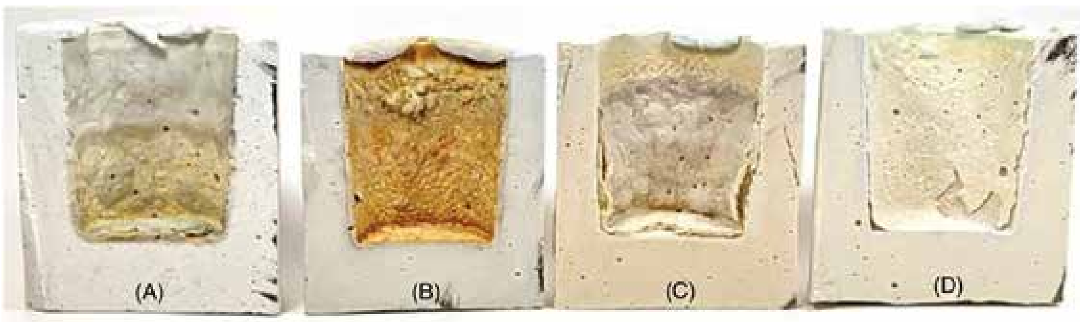
Research News

Longer lasting sodium-ion batteries on the horizon

Researchers at Pacific Northwest National Laboratory developed a sodium-ion battery with greatly extended longevity in laboratory tests. An ingenious shift in the ingredients that make up the liquid core of the battery prevents the performance issues that have bedeviled sodium-based batteries. The new design held 90% of its cell capacity after 300 cycles at 4.2 V. The researchers are experimenting with other designs in an effort to reduce—and eventually eliminate—the need to include cobalt. For more information, visit https://www.pnnl.gov/news.

ceramics in manufacturing

New test method for aluminosilicate refractories offers better insight into real-world alkali attack mechanisms



Credit: Haines et al., *International Journal of Ceramic Engineering & Science* (CC BY 4.0)

Post-test cross-sections of aluminosilicate crucibles that underwent firing with sodium carbonate.

In a recent open-access paper, three researchers from Allied Mineral Products explored a new procedure that would subject aluminosilicate refractory castables to both visual analysis and formal analytical testing after exposure to alkali slag and vapor.

Aluminosilicate castables are used extensively in high-temperature industrial applications due to their desirable properties, ease of availability, and cost advantages. However, in many of these applications, the castables are exposed to alkali in the form of vapors and slags. When these alkalis infiltrate the castables' pores, it can lead to chemical reactions and phase transformations that damage the refractory directly or make it more susceptible to degradation.

There are several ways to reduce the detrimental effects of alkali attacks on refractories, such as by doping the refractory material or reducing the amount of available pore space. To test the effectiveness of these methods, researchers often rely on the crucible cup test (ASTM C987), which replicates an aggressive glass melting furnace environment.

ASTM C987 is a pass/fail test based on visual observation of the refractory after exposure to alkali vapors alone. However, as noted above, aluminosilicate castables are generally exposed to alkalis in various forms, not just vapors. Thus, this test limits a researcher's ability to determine how a refractory may behave in real-world application.

In the new study, the Allied Mineral researchers created five mix designs. Two of the five mix designs were developed with the intent to produce pure mullite ($3Al_2O_3 \cdot 2SiO_2$), while two contained zircon within the mix. The fifth mix was alumina-rich relative to the other designs.

They used these mixes to cast crucibles, which were filled with 20 grams of granular anhydrous sodium carbonate and sealed with lids of the same mix designs. The crucibles were then fired using a multistep firing schedule. After firing, the crucibles were divided into quarters using a wet tile saw, and these quarters were used as representative samples for various tests. Crucibles that did not undergo firing with sodium carbonate were also analyzed for comparison.

Four of the five crucibles remained intact after firing with the sodium carbonate; the fifth alumina-rich mix design failed catastrophically and could not be cross-sectioned. Of the crucibles that could be examined, the researchers found their new procedure allowed them to directly relate the different sodium aluminosilicate phases to corrosion of the refractories.

"Additionally, understanding the mechanism of how these phases can form due to accessible porosity, or lack thereof, is crucial when considering the campaign life of refractory to be used in a corrosive environment," they add.

The open-access paper, published in *International Journal of Ceramic Engineering & Science*, is "Alkali resistance testing methodology and development: Focus on mullite based castables" (DOI: 10.1002/ces2.10131). ■

Ceria helps make miniaturized implantable glucose fuel cells possible

Researchers from Massachusetts Institute of Technology and Technical University of Munich demonstrated the potential of ceramic proton-conducting electrolytes to overcome the limitations of glucose fuel cells featuring polymer proton-exchange membranes.

Glucose fuel cells are being explored as a way to power miniaturized implantable medical devices. These fuel cells allow for significant volumetric scale-down because they do not physically store energy like batteries. Instead, they directly convert the sugar glucose, which is readily available inside the body, into electrical energy through oxidation.

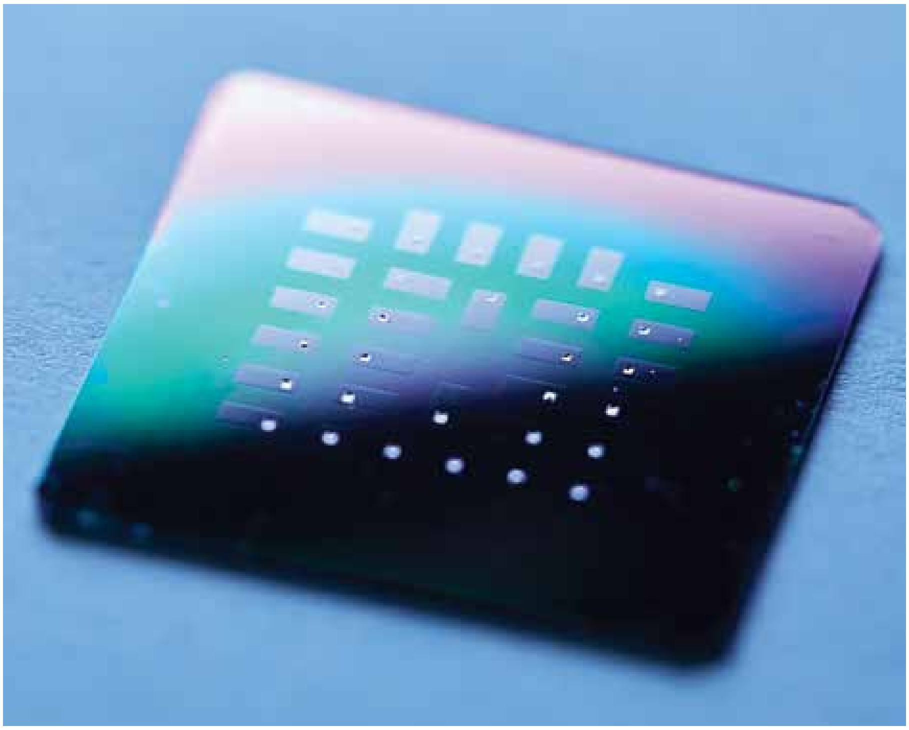
Conventionally, glucose fuel cells use polymer proton-exchange membranes as the electrolyte. Despite good conductivity, these membranes present several drawbacks, including a limit on miniaturization, challenges integrating with silicon-based chip design, and inability for thermal sterilization.

Alternatively, ceramic materials have a long history of use as electrolytes in solid oxide fuel cells and protonic ceramic fuel cells. However, they have not yet been considered for glucose fuel cells.

For this study, the researchers investigated the potential of ceria (CeO_2), a widely used electrolyte in hydrogen fuel cells, because it is nontoxic and biocompatible, stable at temperatures exceeding 1,000°C, displays proton conductivity that allows for operation at body temperature, and has high mechanical stability.

Platinum was chosen for the anode and cathode because it is stable and readily reacts with glucose. The anode was fabricated as a layer of nanoporous platinum with a thickness of 100 nm using a reactive-sputtering method. Because no wet-etching step is required, the process is compatible with ceria. The ceria electrolyte was deposited as thin films of 250 ± 25 nm via pulsed laser deposition.

After optimizing all fabrication steps, the researchers successfully fabricated 150 visually intact glucose fuel cells. Each cell had a thickness of 370 ± 40 nm and measured 300 µm × 300 µm in area. These dimensions made the cells two-orders-of-magnitude thinner than commercial polymer membranes and three times thinner than the next-thinnest device.



Credits: Kent Dayton, Massachusetts Institute of Technology

A silicon chip with 30 individual glucose micro fuel cells, seen as small silver squares inside each gray rectangle.

The fuel cells delivered a peak power density of up to 43 µW/cm^2, which may be the highest power density of any glucose fuel cell to date under ambient conditions. In addition, each cell withstood temperatures up to 600°C. The cells were also exposed to glucose solution and characterized for up to 140 hours, indicating they have long-term stability.

On a structural level, the ceria films had a dense, columnar microstructure with a grain size diameter between 10 and 50 nm. This rough microstructure helped enhance the overall proton conductivity of the electrolyte, reduce mechanical stress in the fuel-cell membrane, block chemical crosstalk between the electrodes, maintain electrochemical potential, and reduce the total device failure rate.

With the proof-of-concept a success, the researchers say there is more work to be done. First, the degradation behavior of the fuel cell system must be understood for future implantation. Then, in vivo studies will be required to verify the fuel cell can operate in a living organism.

The open-access paper, published in *Advanced Materials*, is "A ceramic-electrolyte glucose fuel cell for implantable electronics" (DOI: 10.1002/adma.202109075). ■

Porosity-based heterojunctions may offer efficient and safer optoelectronic implants

University of Chicago researchers created porosity-based silicon heterojunctions that offer an efficient and safer way to perform optoelectronic modulation of tissues.

Advances in flexible implants have almost eliminated the challenge of biomechanical mismatch. However, the lead contained in most of these devices is associated with potential biological complications, such as infection and anatomical position limitations. "Thus, extensive effort has been invested in the development of leadless biomodulation techniques," the researchers write.

The use of semiconductor materials to convert light into an electrical or optoelectronic stimulus is one approach to leadless modulation that has received some attention. Most designs rely on a photodiode configuration that consists of materials with various dopants and/or compositions, leading to high costs, complex fabrications, and potential side effects at biointerfaces.

A much less explored strategy for designing implantable optoelectronic devices involves creating a porosity-based heterojunction out of a single material. In this case, a structural modification (i.e., porosity) is used to achieve different band structures in the device rather than a chemical modification (e.g., dopant).

This design is appealing because it provides a semiconductor–biofluids interface that is free of dopant modulation or metal decoration. It also potentially offers a more deformable biointerface due to the interfacing nanoporous layer.

However, such a porosity-based semiconductor heterojunction has not been used for bioelectronics studies, as far as the UChicago researchers are aware. So, they decided to create porosity-based silicon heterojunctions to test their potential in this application.

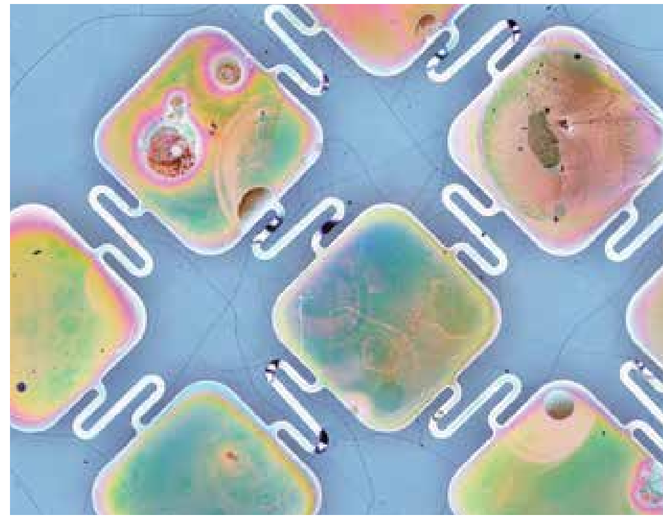
To create the heterojunctions, they used an etching method called self-limiting stain etching, which involves placing silicon wafers in a bath of hydrofluoric acid and chemical oxidant-based solutions. They then subjected the etched wafers to an oxygen plasma treatment to trigger generation of a thin silicon oxide layer on the heterojunction's surface, which theoretically would help boost the signal to biological tissues.

After testing the porosity-based silicon heterojunctions on their own, the researchers interfaced the device with isolated cardiac tissue in a Langendorff apparatus and measured the results. They then used the device to perform in vivo sciatic nerve biomodulation in rats.

These tests demonstrated the free-standing nature of the device, meaning it can be positioned at almost any location. "This suggests that the device can be used for simultaneous stimulation at multiple sites … but without the need for genetic modifications," they write.

In addition, the components can be made biodegradable, meaning the parts would degrade naturally after a few months and would not require a second surgery for removal after fulfilling the desired purpose.

According to the press release, the researchers are working with cardiac researchers at UChicago Medicine to further develop the technology for eventual use in humans. They also are collaborating with the UChicago Polsky Center for Entrepreneurship and Innovation to commercialize the discovery.



Credit: Tian lab, University of Chicago

A microscope image of a silicon membrane after self-limiting stain etching to create porosity-based heterojunctions.

The paper, published in *Nature Materials*, is "Porosity-based heterojunctions enable leadless optoelectronic modulation of tissues" (DOI: 10.1038/s41563-022-01249-7). ■

New design for electrochemical membrane reactors improves long-term stability and efficiency of hydrogen production

Researchers from CoorsTek Membrane Sciences, University of Oslo, and SINTEF Industry in Norway, as well as the Instituto de Tecnologia Química in Spain, designed a new electrochemical membrane reactor that could improve long-term stability and efficiency of hydrogen production.

Hydrogen is one possible long-term energy storage solution that is attracting much attention. However, difficulties associated with transporting hydrogen fuel limit widespread adoption of this technology.

Chemical storage offers a potentially easier way to transport hydrogen. Instead of shipping hydrogen directly, manufacturers will ship hydrogen-rich compounds such as ammonia and methane because they remain stable in more manageable environments. Once these compounds reach their destination, hydrogen can be extracted from the compound and used as fuel.

Electrochemical membrane reactors based on proton ceramic electrolytes offer distinct advantages for extracting hydrogen from hydrogen-rich compounds. Traditional catalytic membrane reactors combine thermochemical catalysts, which facilitate decomposition of the compound, with mechanical pressure to drive hydrogen across a hydrogen-permeable membrane. The permeate emerges at a pressure lower than that of the feed, so additional mechanical pumps are needed to pressurize and compact the hydrogen for storage and transport.

In contrast, electrochemical reactors use voltage to drive hydrogen across a proton-conducting membrane. Because of the solid-state and gas-impermeable nature of the membrane, it is almost assured the hydrogen produced will be free of impurities. Plus, the hydrogen can be pressurized by just increasing the current, so additional equipment is not needed.

Despite recent advances in electrochemical membrane reactors, there are challenges to scaling up these devices for practical application, such as managing the temperature profile across the reactor. When hydrogen is pumped across an electrochemical membrane, it leads to an increase in temperature because of the changes in hydrogen concentrations. At the same time, the decomposition reactions are inherently endothermic and drive the temperature down. Consequently, in a reactor with a simple linear flow, the upstream regime will be much cooler than the downstream regime, and this temperature gradient lowers efficiency.

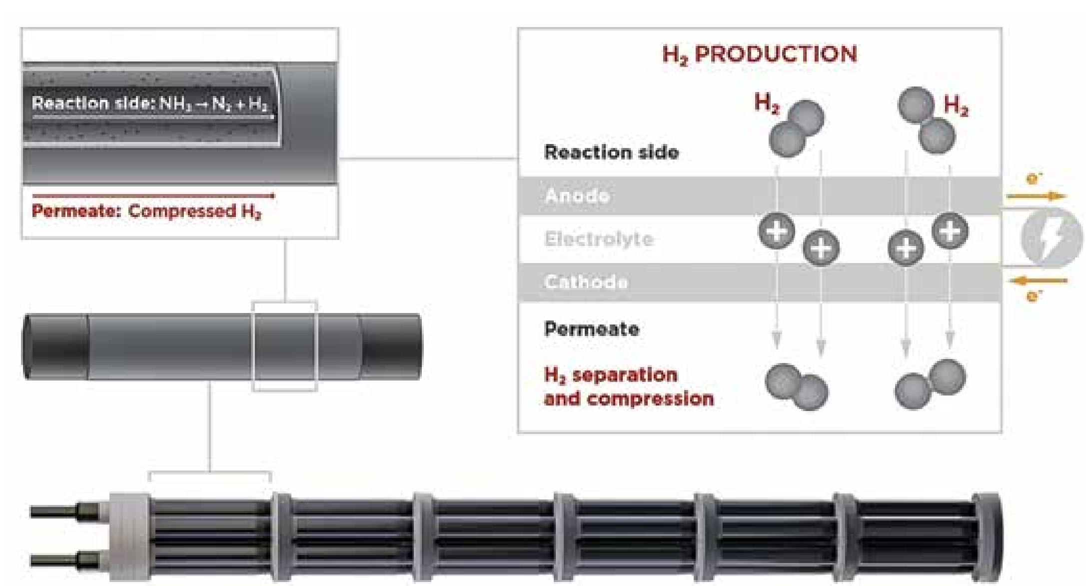
In the recent study, the CoorsTek-led researchers used a $BaZrO_3$-based electrolyte for the reactor, specifically yttrium-doped $BaZrO_3$–$BaCeO_3$. They also used multiphysics simulations and a new expansion-matched metal/glass-ceramic composite interconnect to create an optimized reactor architecture that allows internal heat exchange from exothermic to endothermic processes to minimize auxiliary heat input. This counterflow geometry enabled transfer of the heat generated at the downstream portion of the reactor to the upstream portion of the reactor.

Plus, the new interconnect provided excellent heat transfer and electrical contact between adjacent cells in the reactor, and it matched the thermal expansion behavior of the components, contributing to the reactor's long-term stability.

The researchers reported more than 99% hydrogen extraction efficacy for the system, which exceeds all other values in the literature. Energy loss is an inherent part of transforming energy from one form to another, so achieving such high extraction efficacy is impressive.

A CoorsTek press release states that the next step is to install a pilot plant hydrogen generator at Saudi Aramco's headquarter campus in Dhahran, Saudi Arabia.

The paper, published in *Science*, is "Single-step hydrogen production from NH_3, CH_4, and biogas in stacked proton ceramic reactors" (DOI: 10.1126/science.abj3951). ■



Credit: CoorsTek

Illustration of the new electrochemical membrane reactor designed by CoorsTek-led researchers. It achieved more than 99% hydrogen extraction efficacy

Harmonized testing procedure more accurately determines ionic conductivity of ceramic electrolytes

Researchers from the Karlsruhe Institute of Technology (KIT), the Fraunhofer Institute for Ceramic Technologies and Systems (IKS), and Forschungszentrum Jülich attempted to reduce deviations in ionic conductivity measurements of ceramic electrolytes by developing a harmonized testing procedure.

Oxide ceramic electrolytes are expected to play a key role in solid-state battery technology due to their high thermal stability and ease of fabrication under air atmosphere with readily scalable methods. Two oxides in particular are widely investigated for this purpose: $Li_{1+x}Al_xTi_{2-x}(PO_4)_3$ (LATP) and $Li_7La_3Zr_2O_{12}$ (LLZO). Both electrolytes exhibit ionic conductivities of approximately 10^{-4}-10^{-3} S cm^{-1}, depending on their stoichiometry and processing parameters.

But even for samples that are nominally identical, inconsistent data will show up in the literature due to how ionic conductivity is measured and analyzed. Thus, "It is worthwhile to develop and investigate procedures that provide a clearly defined framework of experimental parameters, which ensures that performance characteristics can be reliably obtained and compared," the researchers write.

Characteristics of their harmonized impedance testing procedure are given below. The first harmonized measurements were conducted at KIT, after which the samples were distributed and measured at IKTS and FZJ. The samples then were sent back to KIT for final measurements after about 5 months, as well as additional aging measurements after several weeks of storage.

Measurement setups

LLZO coin cells were placed in commercial EL-Cell ECC-Std cells in the participating labs. For LATP coin cells, KIT and FZJ contacted them similar to the LLZO coin cells. However, IKTS applied direct coin cell contacting by coaxial contact pins to enable four-point measurements.

Harmonized impedance measurements

Potentiostatic electrochemical impedance spectroscopy (EIS) measurements were conducted with the cells placed inside temperature chambers with active temperature control at 25°C.

Two protocols were established for the EIS measurements. One protocol was used by all three groups for impedance measurements of the LATP samples. IKTS and FZJ employed this protocol for the LLZO samples as well, while the KIT group used a second protocol to better isolate grain and grain boundary effects.

Data analysis

To ensure validity of the experimentally determined impedance data, the system needed to fulfill requirements of linearity, causality, and time-invariance throughout the measurement.

To fulfill the latter criterion, the researchers recorded multiple impedance spectra immediately after mounting the cell into the climate chamber and connecting it to the impedance analyzer. Through simple comparison of the successively acquired spectra in a Nyquist diagram, they identified the thermal equilibrium (and hence time-invariance) based on the observation that there was no significant deviation between two consecutive measurements.

The researchers also performed a validity check for all frequencies by applying the Kramers-Kronig test to the impedance data.

Results

Using the harmonized testing procedure, the researchers successfully reduced deviations among participating labs to differences of less than 1.8% for LLZO and less than 3.1% for LATP. Evaluation of the different error contributions revealed sample temperature is a crucial parameter, as even small temperature deviations of 1 K can lead to an error of about 5%.

"Our study facilitates a reliable assessment of errors that are due to inherent sample properties, ... since the developed measurement and data analysis procedures were harmonized and applied rigorously," the researchers write. As such, "This rigorous approach can prospectively be used as a guideline for accurately determining ionic conductivities of ceramic electrolytes."

The paper, published in *Journal of Power Sources*, is "Guidelines to correctly measure the lithium ion conductivity of oxide ceramic electrolytes based on a harmonized testing procedure" (DOI: 10.1016/j.jpowsour.2022.231323). ■

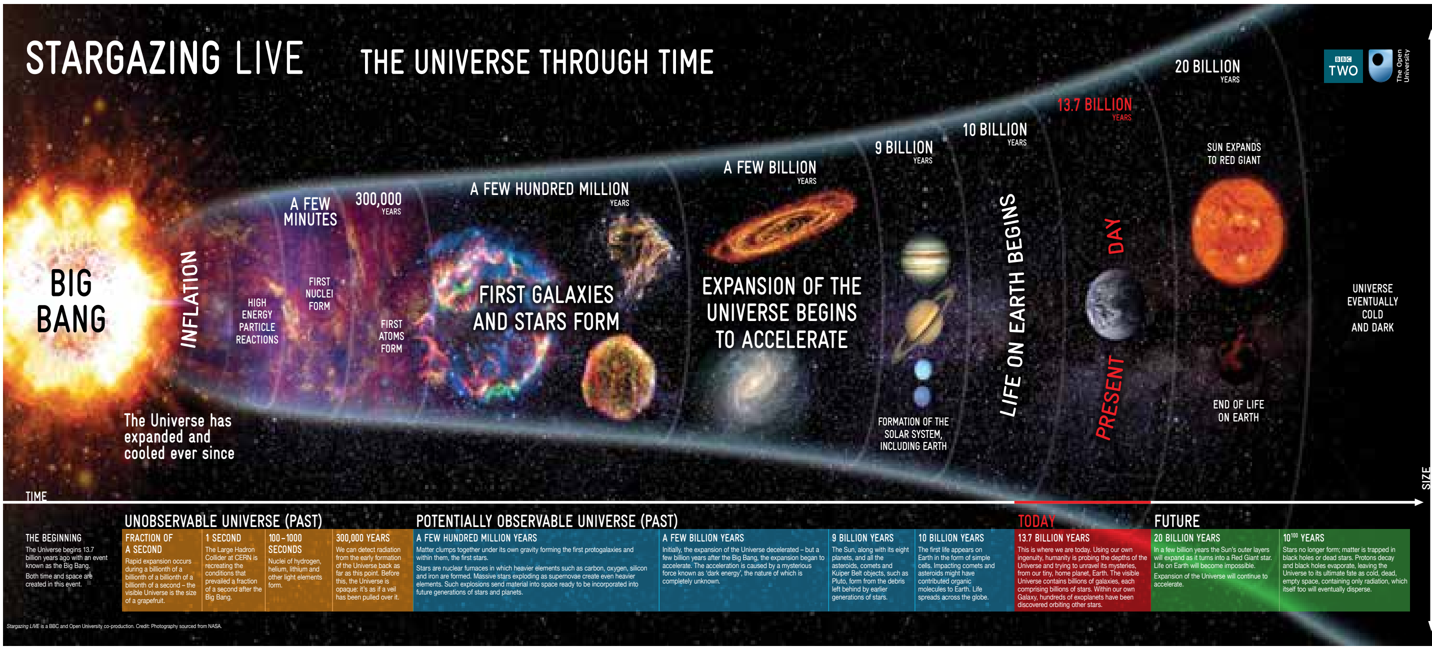


Figure 1. The Big Bang and expansion of the universe versus time. Photography sourced from NASA.

First glass: Formation of silicate in the early universe

By S. K. Sundaram

Silicate glass—the basis of the world's most commercially important glasses—first formed more than 7 billion years ago.

Melting of silicate glasses dates to about 6000 BCE, while evidence of glass tools dates to 10000 BCE.[1] However, geological glasses that formed by impact and other processes are much older, for example, Libyan Desert glasses are about 28.5 million years old.[2]

Chondrules are some of the oldest known examples of geological glasses. These small, spherical, glass-rich inclusions are found in chondrites, i.e., stones from meteorites.[3] The glass matrix contains several minerals, namely olivines and pyroxenes, along with metals and sulfides made of magnesium, iron, calcium, and nickel.[4] Silica content of these glassy matrices varies over 40–85 wt.%. Chondrules are 4,567.32 ± 0.42 to 4,564.71 ± 0.30 million years old.[5] Chondrites also have other inclusions rich in calcium and aluminum condensed 4,567.30 ± 0.16 million years ago. These time scales, which are supported by uranium isotopic measurements, closely match with the estimated age of our solar system.

While cauldrons in the cosmos continue to reveal complex chemistries,[6] the exact origin of glasses remains an exciting puzzle. To determine when and where the very first glass was birthed in the universe, we need to go back in time to the Big Bang, look closely, and follow the timeline of expansion of the universe and nucleosynthesis processes.

Doing so will allow us to determine when chemical elements, particularly oxygen and silicon, formed and interacted to form silica tetrahedra, the building block of silicate glasses and rock-forming minerals that remain in abundance in the earth's crust even today. That will perhaps help us in defining the very moment the first glass was born.

The Big Bang and slow birth of the universe

The Big Bang occurred about 14 billion years ago. As of 2018, astronomers estimated the age of the universe at 13.787 ± 0.020 billion years. Figure 1 shows an overview of the Big Bang, the universe, its expansion, and timeline. In the span of about 13.8 billion years, one can observe evolution of hierarchical structures on all scales encompassing nuclei, elements, galaxies, and planets in the universe.

Though the first atom formed about 300,000 years after the Big Bang, it took a few hundred million years before oxygen and silicon atoms formed and a few more billion years before other heavy elements came into existence in the solar system. After about 9 billion years, the sun, the planets, asteroids, comets, and other objects formed out of debris left behind by earlier generations of stars. The first sign of life was not until about 10 billion years after the Big Bang.

Stellar births result from the collapse of small condensation areas scattered throughout large molecular clouds in the galactic disks. As the core becomes hotter, the star can start "burning," thus producing energy through nuclear fusion via stellar nucleosynthesis.[8] Initial mass of the star dictates whether it continues to burn or dies. If the star weighs less than about 8 solar masses (M⊙), it will burn helium and become unstable, ending up as white dwarfs, which contain carbon and oxygen produced by helium burning. The solar mass M⊙ is a standard unit of mass, equal to about 2×10^{30} kg, to show the masses of stars and other objects.

If a star weighs more than about 8 M⊙, the burning will continue with carbon, neon, oxygen, and silicon as fuels, leading to formation of heavier nuclei. As the outer shell is a cooler and not dense

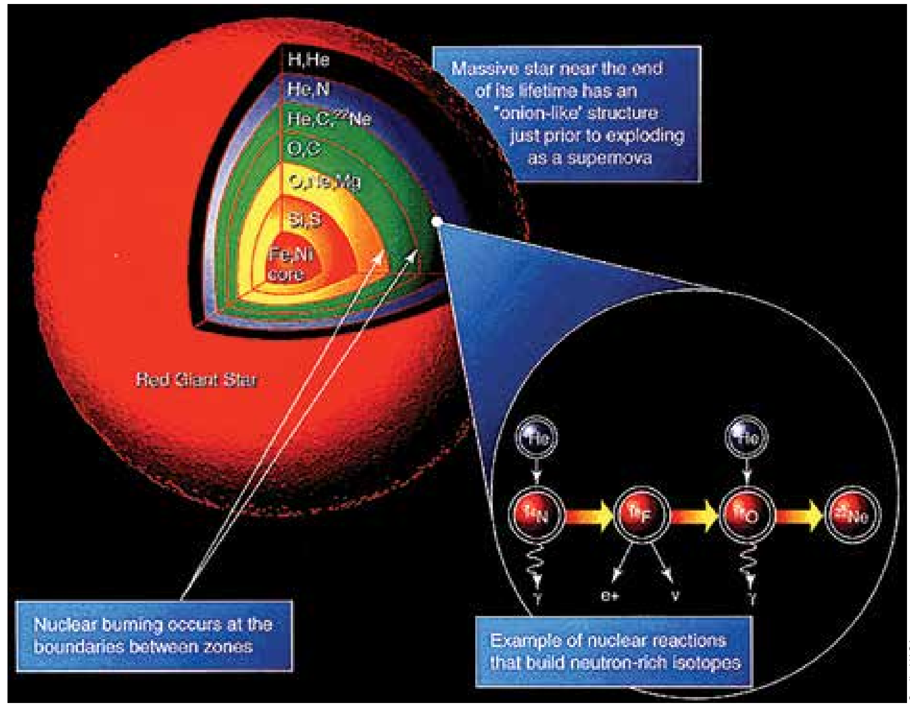


Figure 2. Massive star with onion-like structure.

region, the burning happens with a specific shell chemical composition. With hydrogen burning, for example, hydrogen burns into helium forming the outer shell. The process continues sequentially at interfaces of carbon, oxygen, neon, and silicon burning shells. This process leads to formation of an onion-like, presupernova structure illustrated in Figure 2. The most important reaction during the oxygen burning process, i.e., $^{16}O + ^{16}O \rightarrow ^{28}Si + ^{4}He$, occurs at about 2×10^9 K. When the silicon burning begins, the final stage at about 5×10^9 K produces a series of reactions starting with the photodisintegration of ^{28}Si: $^{28}Si + \gamma \rightarrow ^{24}Mg + ^{4}He$. Then, the ^{4}He continues to produce heavier nuclei via successive capture reactions. Heavy elements settle into layers.

Table 1. Summary of stellar nucleosynthesis and evolutionary time scales for a 15 M⊙ star. Adapted from Reference 9. *Credit: Longair, Cambridge University Press*

Burning stage	Products	Time scale	Temperature (10^9 K)	Density (gm cm^{-3})
Hydrogen	He, N, Na	11 million years	0.035	5.8
Helium	C, O	2 million years	0.18	1390
Carbon	Ne, Na, Mg, Al	2,000 years	0.81	2.8×10^5
Neon	O, Mg, Al	0.7 year	1.6	1.2×10^7
Oxygen	Si, S, Ar, Ca	2.6 years	1.9	8.8×10^6
Silicon	Fe, Ni, Cr, Ti	18 days	3.3	4.8×10^7
Iron core collapse	Neutron star	1 second	>7.1	$>7.3 \times 10^9$

Elemental oxygen and silicon come into contact for the first time during their burning cycles. At the stage of silicon burning, equilibrium ratios of all nuclear products up to ^{56}Fe is reached and energy production ceases, an event called the "iron catastrophe." Beyond that, neutron capture processes will be required to produce elements heavier than iron. The stars of mass greater than 8 M⊙ become supernovas. Explosive burning continues, leading to formation of other elements. Table 1 shows a summary of stellar nucleosynthesis for a large star of 15 M⊙.[9]

Nucleosynthesis and abundance of elements

The earliest history of the universe involved primordial nucleosynthesis of the nuclei of the light elements. After the Big Bang's short inflationary period, there was a hot soup of particles at a temperature of about 10^{15} K. Within a millisecond, the universe cooled to a few trillion degrees (10^{12} K). The hot

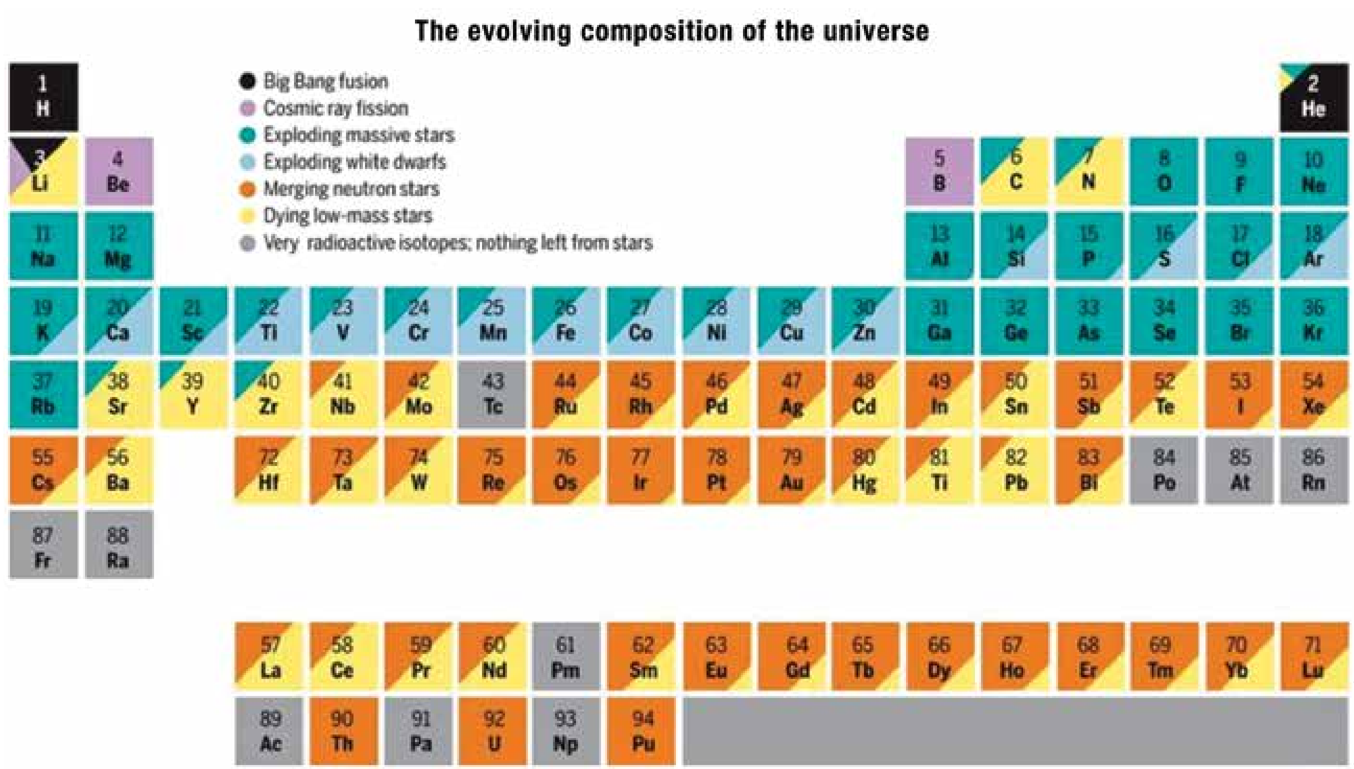


Figure 3. Nucleosynthesis and elements in our solar system. Each element is color-coded by the relative contribution of nucleosynthesis sources, scaled to the time of solar system formation.[10] Reprinted with permission.

plasma was composed of many particles including neutrons, protons, electrons, and photons. As the universe cooled to a billion kelvins (10^9 K), deuterium (^{2}H) formed followed by ^{4}He via fusion. Additional reactions between protons, neutrons, ^{3}He, and ^{4}He led to production of ^{7}Li. On further cooling, the rate of nucleosynthesis slowed down significantly. Within the first three minutes,[7] the primordial process ended with two elements, 75% hydrogen and 25% helium, and the universe was left with trace amounts of ^{2}H, ^{3}He, ^{4}He, and ^{7}Li for a few hundred million years. All other naturally occurring elements were created through stellar evolution and explosions, i.e., stellar nucleosynthesis.

A recent review paper captures a high-level view of when and how nucleosynthesis produced naturally occurring elements, as shown in Figure 3.[10] Out of all primordial elements, predominantly 75% hydrogen and 25% helium and trace elements, only 2% were consumed since the Big Bang to produce all naturally occurring elements in the periodic table.

Figure 4 shows the abundance of these elements in Earth's crust. Note the number of atoms is normalized to silicon and all rock-forming elements that are abundant in the crust. As the Earth's core is hotter, various elements formed and settled, leaving distinguishable lithophilic (rock forming) elements in the crust and siderophilic (metal-rich) elements in the bulk. Dense elements such as iron and nickel settled down closer to the core. Light materials such as silica partitioned in the crust. This settling had a significant impact on current geographic distribution and availability of these elements.

Presolar materials

Pre-solar system (presolar) grains range in size from nano- to micrometers. They contain many high-temperature minerals and amorphous phases. Some silica and silicate minerals (e.g., olivine, pyroxene) have been identified. These grains formed in many different environments, including explosive deaths of supernovae several billions of years before the solar system formed, thus challenging the current estimate for age of the oldest chondrule glasses at about 4.6 billion years.

Since the discovery of presolar silicate grains in the 2000s, hundreds more have been identified and reported in the literature.[12] Two supernova silica grains in some chondrites reported in 2013 were interpreted to result from condensation of silica dust in supernova ejecta, which cooled rapidly under nonequilibrium conditions.[13] The authors attribute formation of these grains to reactions over time during star formation. These observations are supported by oxygen isotopic measurements, Auger spectroscopy, transmission electron microscopy, and surface characterization using nanoscale secondary ion mass spectrometry (NanoSIMS) data.

Several large presolar silicon carbide grains from a meteorite were reported in 2020.[14] These grains were exposed to cosmic rays several million to a few billion years before the existence of the solar system. The authors hypothesized these grains condensed less than 4.9 billion years ago due to an event of enhanced star formation, which happened about 7 billion years ago, forming many more stars than normal at that time.

In 2021, several presolar silicate and oxide grains in chondrites found in northwest Africa that condensed in different

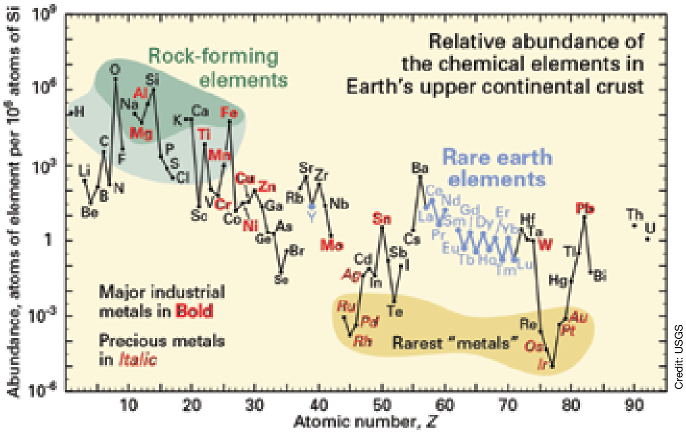


Figure 4. Abundance of elements in Earth's crust.[11]

stellar environments were reported.[15] The relative difference in element distribution from silicates and silica along the fine-grained chondrule rims are due to preferential destruction of silicates due to terrestrial weathering. Isotopic measurements, NanoSIMS, scanning electron microscopy, and mapping of magnesium iron and silicon confirmed these observations. SEM and maps are shown in Figure 5. The dashed turquoise line shown in the figure marks the outer boundary of the rims in the sample. Scale bars shown on the images mark 500 µm.

Conclusion

Determining when and where the very first glass was birthed is complex as one needs to connect various nucleosynthesis processes happening in elementary particles, nuclei, stars, and galaxies over billions of years to reach an estimate. Considering that the earliest contact between oxygen and silicon was a few hundred million years to a billion years after the Big Bang and that presolar grains made of amorphous silica, silicates, and other phases condensed out under various stellar formation conditions, the oldest glasses were evidently billions of years older than the start of our solar system. While the universe continues to reveal and surprise, the birth of the first silicate glass was likely at least 7 billion years ago.

About the author

S.K. Sundaram is an Inamori Professor of Materials Science and Engineering at The New York State College of Ceramics, Alfred University. He is also a haiku poet and literary writer. Contact Sundaram at sundaram@alfred.edu.

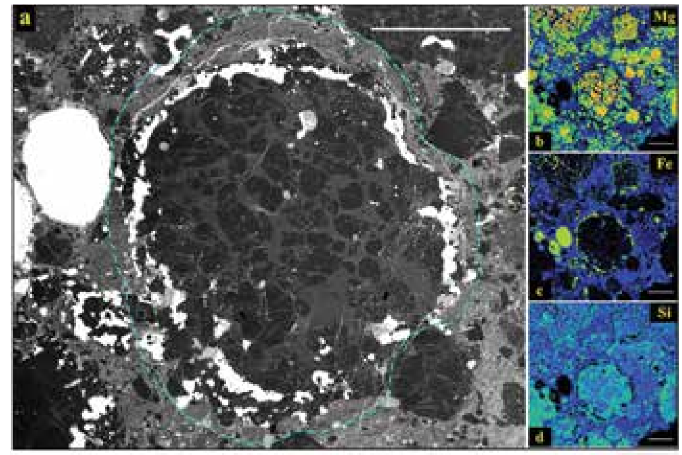


Figure 5. SEM backscattered image and elemental maps of a chondrule sample.[15] Reprinted with permission.

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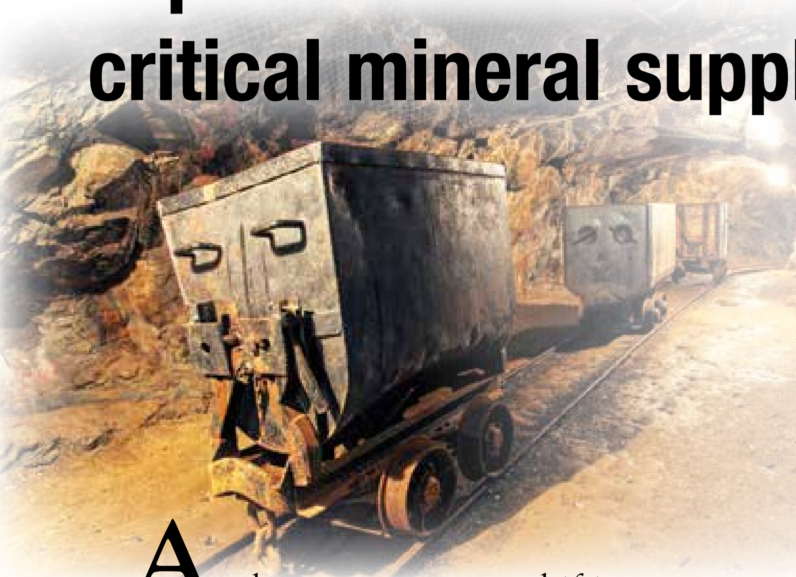
WHERE MATERIALS INNOVATION HAPPENS

Economy begins to rebound as the US expands efforts to strengthen domestic critical mineral supply chains

By Lisa McDonald



As the economy starts shifting back into gear following closures during the global COVID-19 pandemic, the U.S. government continues advancing efforts to strengthen domestic critical mineral supply chains, as described in the annual United States Geological Survey *Mineral Commodity Summaries* report.[1]

The *Mineral Commodity Summaries* spotlights events, trends, and issues from the past year in the nonfuel mineral industry. Every August, the *ACerS Bulletin* provides a look at some of the key facts covered in the report, including statistics on production, supply, and overall market for more than 90 minerals and raw materials.

In 2021, the estimated total value of nonfuel mineral production in the United States increased by 12% from 2020 to $90.4 billion. The total value of industrial minerals production increased as well, by 6% to $56.6 billion. Of this total, $29.2 billion came from construction aggregates production. Crushed stone accounted for the largest share of total U.S. nonfuel mineral production value in 2021 with 21%.

Last year saw increases in the consumption of nonfuel mineral commodities in commercial construction, steel production, and automotive and transportation industries as the economy restarted following closures during the global COVID-19 pandemic. For the metals sector, the copper, iron ore, steel, and zinc industries were particularly affected by increased demand from manufacturing.

Most industries experienced widespread supply chain disruptions during 2021, particularly in cargo transportation.[2] A lack of truck drivers to remove cargo containers caused delays in offloading ships at docks, leading to ports running out of space to store containers. Cargo ships were then forced to remain at sea until space was available to unload them.

The U.S. continues to rely on foreign sources for raw and processed mineral materials. In 2021, imports made up more than one-half of the U.S. apparent consumption for 47 nonfuel mineral commodities, and the U.S. was 100% net import reliant for 17 of those. Of the 35 minerals or mineral material groups identified as "critical minerals," the U.S. was 100% net import reliant for 14 of them, and an additional 15 critical mineral commodities had a net import reliance greater than 50% of apparent consumption.

In 2021, several U.S. government efforts were taken to strengthen U.S. critical mineral supply chains. For example, continued from 2020, the U.S. Department of Defense awarded technology investment agreements to establish rare earth element separation facilities in Texas[3] and California.[4] In April 2021, the U.S. Department of Energy awarded $19 million for 13 projects to support production of rare earth elements and critical minerals essential for clean energy projects.[5] In September 2021, DOE awarded $30 million in funding for 13 university- and national laboratory-led research projects focused on developing substitutes for, diversifying the supply of, and improving the reuse and recycling of rare earth elements and platinum-group elements that are critical for many clean energy and high-tech applications.[6] Also in September, the U.S. Department of Defense's Office of Industrial Policy launched the "Critical Minerals from Coal Ash" pilot project, which will develop next-generation technologies for recovery of critical minerals and rare earth elements from domestic coal ash.[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. It is followed by a two-page infographic by IMFORMED that focuses specifically on refractory raw materials. Readers are encouraged to access the complete USGS report at https://doi.org/10.3133/mcs2022.

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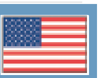
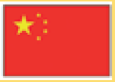
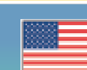
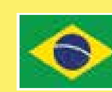
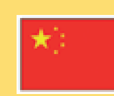
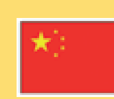
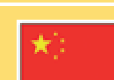
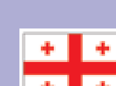
USGS MINERALS COMMODITY SUMMARIES

Leading producer highlights

	End-use industries	Trends in global production	U.S. production	U.S. import/export	World reserves	Leading producer
BAUXITE AND ALUMINA	Abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills	2.9% increase for alumina; 0.3% decrease for bauxite	1 million tons of alumina	>75% net import reliance for bauxite; 58% net import reliance for alumina	55 to 75 billion tons of bauxite	Bauxite  Alumina 
BORON	Glass, ceramics, abrasives, chemicals, semiconductors	Cannot be calculated	Withheld	Net exporter	Adequate	
CEMENT	Construction	4.5% increase for cement; no change for clinker	92.0 million tons of cement; 79.0 million tons of clinker	18% net import reliance	N/A	
CLAYS	Tile, sanitaryware, absorbents, drilling mud, construction, refractories, paper, absorbents	1.1% decrease for bentonite; 1.8% increase for Fuller's earth; 3.0% decrease for kaolin	25.0 million tons (52.0% common clay; 17.2% bentonite; 16.4% kaolin; 14.4% other)	Net exporter	Extremely large	Bentonite  Kaolin 
FELDSPAR	Glass, tile, pottery	12.9% increase	400,000 tons (marketable production)	32% net import reliance	More than adequate	
GALLIUM	Integrated circuits, optoelectronic devices	24.0% increase	None (primary)	100% net import reliance	Estimate unavailable	

	End use industries	Trend in global production	U.S. production	U.S. import/export	World reserves	Leading producer
GRAPHITE (NATURAL)	Batteries, brake linings, lubricants, powdered metals, refractory applications, steelmaking	3.4% increase	None	100% net import reliance	>800 million tons	
INDIUM	Flat-panel displays, alloys, solders, compounds, electrical components, semiconductors	4.2% decrease	None	100% net import reliance	Estimate unavailable	
IRON AND STEEL	Construction, transportation (auto), machinery, equipment, energy	6.4% increase for pig iron; 5.8% increase for raw steel	22 million tons of pig iron; 87 million tons of steel	10% net import reliance	N/A	
KYANITE	Refractories, abrasives, ceramic products, foundry products	Cannot be calculated	81,000 tons	Net exporter	Significant	Kyanite  Andalusite 
LITHIUM	Batteries, ceramics, glass, lubricating greases	17.5% increase	Withheld	>25% net import reliance reliance	Significant	
NIOBIUM	Steels, superalloys	9.7% increase	None	100% net import reliance	More than adequate	
RARE EARTHS	Catalysts, ceramics, glass, metallurgical alloys, polishing	14.3% increase	43,000 tons (mineral concentrates)	>90% 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	6.6% increase	12 million tons	Net exporter	Practically inexhaustible	
TITANIUM DIOXIDE (PIGMENT)	Paints, plastic, paper, catalysts, ceramics, coated textiles, floor coverings, inks, roofing granules	N/A	1.1 million tons	Net exporter	Data not available	
YTTRIUM	Catalysts, ceramics, electronics, lasers, metallurgy, phosphor	N/A	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	1.6% decrease	87,000 tons	Net exporter	No estimate available	

IMFORMED
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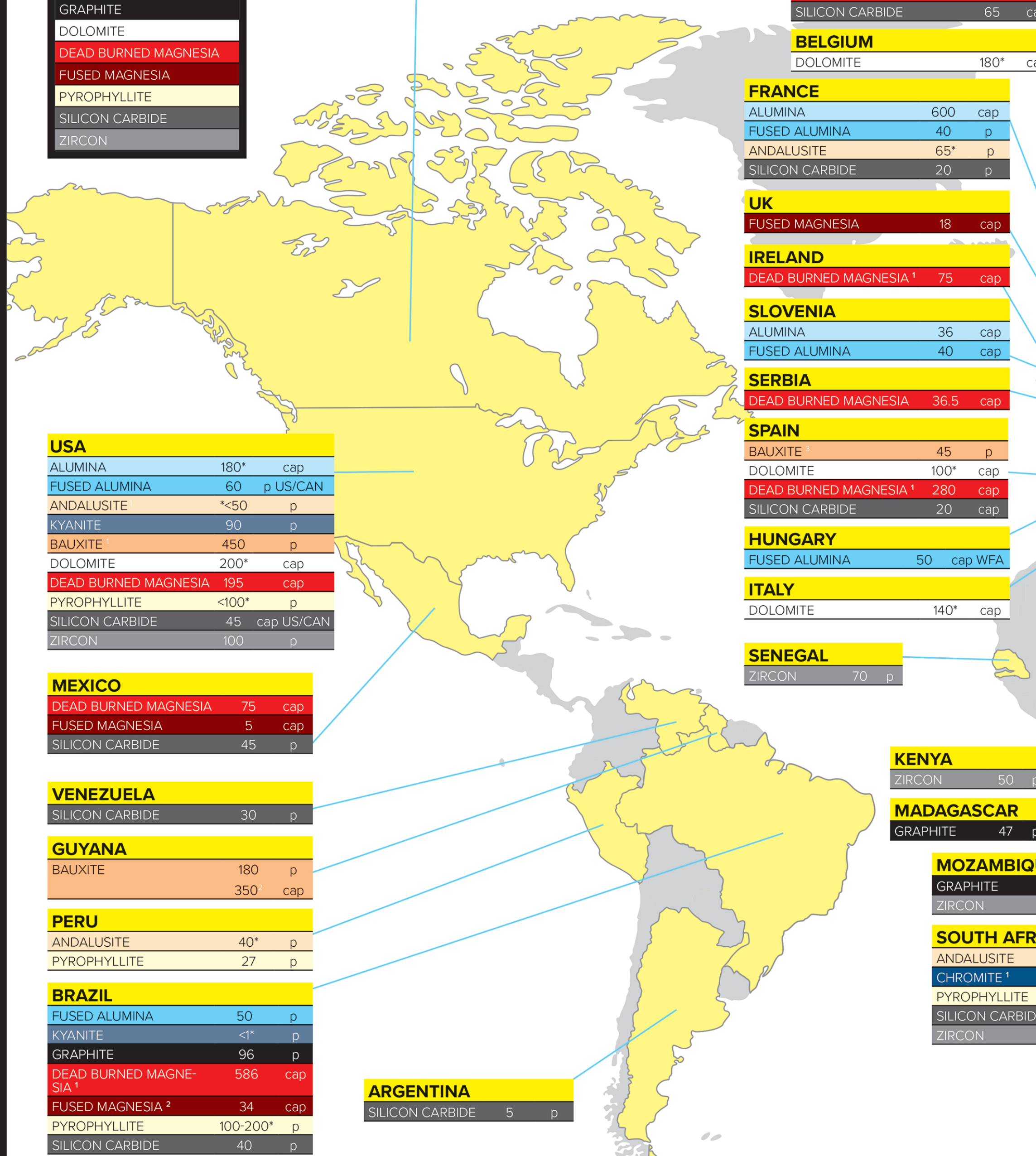
Refractory raw

KEY – see notes below
ALUMINA
FUSED ALUMINA
ANDALUSITE
KYANITE
SILLIMANITE
BAUXITE
CHROMITE
GRAPHITE
DOLOMITE
DEAD BURNED MAGNESIA
FUSED MAGNESIA
PYROPHYLLITE
SILICON CARBIDE
ZIRCON



CANADA		
GRAPHITE	40	p
DOLOMITE	40*	cap
FUSED MAGNESIA	14	cap
PYROPHYLLITE	156*	p

NORWAY		
GRAPHITE	16	p
FUSED MAGNESIA [2]	80	cap
SILICON CARBIDE	80	p

GERMANY
ALUMINA
FUSED ALUMINA
SILICON CARBIDE

NETHERLANDS		
ALUMINA	100	cap
DEAD BURNED MAGNESIA	175	cap
SILICON CARBIDE	65	cap

AUSTRI
FUSED AL
DOLOMITI
DEAD BUR
FUSED MA

SI
DE

BELGIUM		
DOLOMITE	180*	cap

FRANCE		
ALUMINA	600	cap
FUSED ALUMINA	40	p
ANDALUSITE	65*	p
SILICON CARBIDE	20	p

UK		
FUSED MAGNESIA	18	cap

IRELAND		
DEAD BURNED MAGNESIA [1]	75	cap

SLOVENIA		
ALUMINA	36	cap
FUSED ALUMINA	40	cap

SERBIA		
DEAD BURNED MAGNESIA	36.5	cap

SPAIN		
BAUXITE [3]	45	p
DOLOMITE	100*	cap
DEAD BURNED MAGNESIA [1]	280	cap
SILICON CARBIDE	20	cap

HUNGARY		
FUSED ALUMINA	50	cap WFA

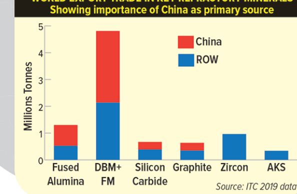
ITALY		
DOLOMITE	140*	cap

USA		
ALUMINA	180*	cap
FUSED ALUMINA	60	p US/CAN
ANDALUSITE	*<50	p
KYANITE	90	p
BAUXITE [1]	450	p
DOLOMITE	200*	cap
DEAD BURNED MAGNESIA	195	cap
PYROPHYLLITE	<100*	p
SILICON CARBIDE	45	cap US/CAN
ZIRCON	100	p

MEXICO		
DEAD BURNED MAGNESIA	75	cap
FUSED MAGNESIA	5	cap
SILICON CARBIDE	45	p

SENEGAL		
ZIRCON	70	p

WORLD EXPORT TRADE IN KEY REFRACTORY MINERALS
Showing importance of China as primary source



Source: ITC 2019 data

VENEZUELA		
SILICON CARBIDE	30	p

GUYANA		
BAUXITE	180	p
	350 [2]	cap

PERU		
ANDALUSITE	40*	p
PYROPHYLLITE	27	p

BRAZIL		
FUSED ALUMINA	50	p
KYANITE	<1*	p
GRAPHITE	96	p
DEAD BURNED MAGNESIA [1]	586	cap
FUSED MAGNESIA [2]	34	cap
PYROPHYLLITE	100-200*	p
SILICON CARBIDE	40	p

ARGENTINA		
SILICON CARBIDE	5	p

KENYA		
ZIRCON	50	p

MADAGASCAR		
GRAPHITE	47	p

MOZAMBIQUE		
GRAPHITE	100	p
ZIRCON	50	p

SOUTH AFRICA		
ANDALUSITE	190*	p
CHROMITE [1]	2,000*	p
PYROPHYLLITE	98	p
SILICON CARBIDE	55	cap
ZIRCON	370	p

NOTES

Only primary country mineral sources for nonmetallic grades are shown, not entire world production; there maybe other smaller volume country sources for certain minerals.

p latest reported production
cap total production capacity
(Data in '000s tonnes)
* estimate

Alumina: ie. "Speciality aluminas," derived from chemical grade aluminas (world total production approx. 8.4m tpa), of which approx. 40% speciality aluminas incl. calcined alumina, tabular alumina, sintered spinel; about 60% of speciality aluminas (approx. 2–3m tpa) is consumed by refractories, remainder in ceramics, catalysts, abrasives, polishing.

Fused alumina: includes both white fused alumina (WFA) and brown fused alumina (BFA), unless designated where known; often difficult to secure accurate data on precise fused mineral production; many fusion plants produce either WFA, BFA, and/or other fused products; about 60% of BFA and 50% of WFA is consumed by refractories, the remainder for each goes to abrasives.

Andalusite:[1] mineral assemblage of andalusite-pyrophyllite-quartz mined in North Carolina; mostly consumed in refractories (≥90%), smaller volumes are used in foundry, ceramics, & abrasives.

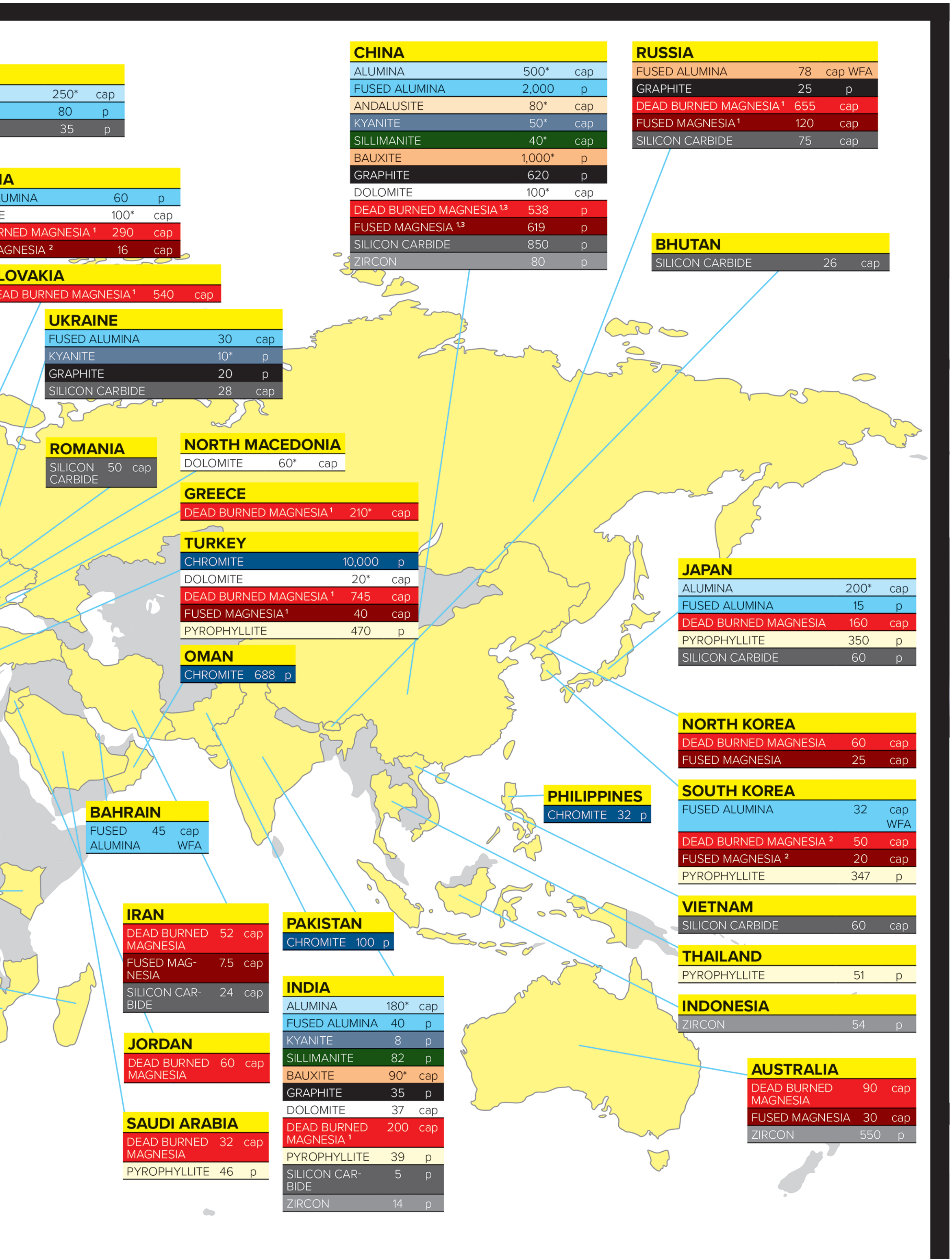
Kyanite: mostly used in refractories, also in ceramics, foundry, minor use in abrasives.

Sillimanite: mostly used in refractories, also in ceramics, foundry, minor use in abrasives.

Bauxite: i.e., refractory grade calcined bauxite unless indicated; 1 raw nonmet. bauxite/bauxitic kaolin, some calcined for refractories; 2 raw high grade refractory bauxite, exported; 3 calcined, imported raw from Guyana;most raw bauxite (96%; total prod. 380m t) for met-allurgical route (smelter grade alumina (94%) & chemical grade (6%) alumina), remainder (4%) for nonmet. uses.

Chromite:[1] S. Africa nonmet. grades (44-48% Cr_2O_3); other countries include all grades produced (Philippines, Turkey, Oman noted for refractory grades); FeCr alloy market dominates chromite demand, which can influence non-met. grade availability; about 96% chromite is consumed in metallurgical applications, as little as <1% is used in refractories, 2% chemicals, and 1.5% foundry.

material world sources map



Graphite: natural flake graphite, which is used in refractories; total production is 0.8–1.0m tpa; refractories consume about 30%, then batteries, 26%, foundry, 22%, recarburizers, 4%, friction, 3%, lubricants 2%, other 13%.

Dolomite:[1] proposed Austrian cap planned for 2021;[2] Belgian capacity expected to close down 2020/21; refractories is a niche market supplied by limited sources of refractory grade dolomite (also used as steel flux); most dolomite (80%) used in construction aggregate, followed by a wide range of applications incl. chemicals, agriculture, environment, fillers.

Magnesia:[1] Partly captive production;[2] Mainly captive production; 3 China: capacity utilization rates may be ≤50%, since 2017 much capacity has been closed, moth-balled, or in upgrade; most DBM/FM is used in refractories, very small volumes of DBM are used in welding, small volumes of FM are used in electrical insulation; most DBM/FM producers, especially in China, supply their own integrated refractory plants.

Pyrophyllite: often hosted within unique mineral assemblages (i.e., rock), e.g., agalma-tolite in Brazil, roseki in Japan, "andalusite ore" in USA; also used in ceramics, fiber glass, plastics, pulp & paper, agriculture, paint & coatings, rubber.

Silicon carbide: an estimated 10–25% is used in refractories, 50–70% in metallurgy, 10–25% in abrasives.

Zircon: about 15% is used in refractories; ceramics, 50%; zirconia & chemicals, 20%; foundry, 15%.

Creator & editor:
Mike O'Driscoll
mike@imformed.com

Advertising/enquiries for more copies:
Ismene Clarke
ismene@imformed.com

Design: Tina Eldred

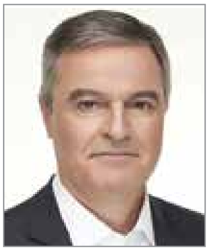
Website:
www.imformed.com

Sources: IMFORMED; industry sources, plus: Benchmark Mineral Intelligence, British Geological Survey, Dept. Mineral Resources South Africa, Indian Bureau of Mines, Mines & Geosciences Bureau Philippines, Pakistan Bureau of Statistics, Recursos Minerais de Minas Gerais, Refractories Window, Roskill Information Services, U.S. Geological Survey.

Fostering sustainability in the refractories industry

By Lisa McDonald

In an interview, RHI Magnesita chief technology officer Luis Bittencourt discusses the importance of improving sustainability in the refractories industry and how RHI Magnesita is working toward that goal.


Bittencourt

From steelmaking to glass manufacturing to paper mills, refractories play an essential role in ensuring the continuous operations of the industries upon which our society relies.

In recent years, the role of refractories in ensuring sustainability of our industrial practices is gaining prominence as well. During the Unified International Technical Conference on Refractories in Chicago, Ill., in March 2022, RHI Magnesita chief technology officer Luis Bittencourt talked with *Bulletin* associate managing editor Lisa McDonald about the importance of improving sustainability in the refractories industry and how RHI Magnesita is working toward that goal. What follows is condensed from that conversation.

Aiming for net-zero emissions

Refractories are, for the most part, based on natural raw materials. Carbonates are the most used minerals in refractories, and these minerals contain CO_2 in their crystal structure. As such, the manufacturing of refractory products releases a large amount of greenhouse gas emissions.

With the increasing attention to climate change and its effects, the refractory industry in general must change if we want to see our planet in a better condition. However, because there is what we call "organic CO_2" in our minerals, the reduction of process-related emissions is complex and cannot be reduced without significant investments.

We at RHI Magnesita have very ambitious targets of becoming a net-zero company. We have several initiatives at a variety of stages to achieve this goal. For initiatives in the early stages, our board recently approved an investment of 50 million euros just for R&D and pilot plants for CO_2 capture, usage, and storage. Finding ways to reuse the captured CO_2 is the most challenging part because capturing is, I would say, more mature in terms of technology readiness level than reusing it. However, we do already have industrial applications for the NO_x and SO_x emissions, which is also an important part of our sustainability targets.

For initiatives in more advanced stages, the number one initiative currently is our global recycling program. We have a target to increase our recycling rate to 10% by 2025. This program is the most important part to achieving our CO_2 emission reduction target of 15% by 2025.

We also have a global initiative to transition which fuels we rely on, from coal or coke to natural gas. We are planning for the possibility of hydrogen becoming a more common energy source too. We are not only investigating the use of hydrogen in our processes to produce refractories, but we are also preparing ourselves to supply our customers the necessary and different refractory products that they will need when they start using hydrogen at much higher volumes. Our hydrogen projects are at lab-scale at this point.

We also are working together with customers on projects where we supply them with low-carbon footprint products, such as our Ankral LC series product line, which is used in the cement industry. This partnership that we have with customers helps them reduce their emissions.

Sustainability includes people

Manufacturing processes and materials are not the only components of sustainability. Cultivating a diverse and inclusive culture within a company is also important to long-term success. At RHI Magnesita, we already achieved our target of a 33% share of women on our Board by 2025. We are continuing to improve on the number of women in senior roles.

We are changing our recruitment process as well to make sure that we attract more women. For example, we are trying to make jobs ads in such a way that women will feel especially attracted to apply for the position. Also, we hold trainings where our internal experts teach other women about their special topics, so you can broaden your own expertise on what our company does, which is also very important. And then we have trainees, where we have more women than men. We want to make sure that we have a good mix, but in this case, we even have more young women to fill the pipeline for future leaders. And, of course, networking is very important. We go to universities so we can network with young women and show them that we are a good place to work.

Personally, the more I work with sustainability, the more I like it because it touches on a different part of our sentiments. The challenge of becoming net zero is extremely motivating for me. To be able to really contribute to the CO_2 initiatives and projects through resourceful methods, that energizes me a lot.

Learn more about RHI Magnesita's sustainability efforts at https://www.rhimagnesita.com/our-sustainability.

Contact Patrizia Pappacena, head of corporate communications, at patrizia.pappacena@rhimagnesita.com with questions. ■

Progress toward sustainability targets

Material issue	Targets by 2025 vs 2018 baseline year	Progress in 2021		2018	2019	2020	2021
1. CO_2 emissions	Reduce by 15% per tonne of product —Scope 1, 2, 3 (raw materials)	CO_2 intensity decreased by 3.7% compared to the base year	Absolute (t CO_2)	5,453,000	4,681,000	4,277,000	4,878,000
			Relative (t CO_2/t)[1]	1.89	1.85	1.96	1.82
2. Energy	Reduce by 5% per tonne of product	Energy efficiency improved by 4.7% compared to 2020 and 2.7% compared to the base year (2018)	Absolute energy consumption (GWh)	5,718	5,227	4,577	5,184
			Relative (MWh/t)[1]	1.98	1.93	2.03	1.93
3. Recycling	Increase use of secondary raw materials to 10%	Use of SRM increased to 6.8%	Use of secondary raw materials	3.8%	4.6%	5.0%	6.8%
4. Diversity	Increase women on our Board and in senior leadership to 33%	Women now account for 38% of our Board. Share of women in leadership decreased to 22%	Board	7%	23%	25%	38%
			EMT and direct reports	12%	17%	25%	22%
5. Safety	Maintain LTIF at <0.5 (goal: zero accidents)	Lost time injury frequency ("LTIF") increased 38% over 2020	per 200,000 hours worked	0.43	0.28	0.13	0.18
6. NOx and SOx emissions	Reduce by 30% by 2027 (vs 2018), starting with China by 2021	30% reduction in NOx and SOx achieved in China already; work now focuses on US operations	China —target achieved 2021		Europe—target 2027	South America —target 2027	North America —target 2025

1 Adaptations in line with the Greenhouse Gas protocol and refinement in reporting result in updated CO_2 and energy efficiency figures for 2018-2021.

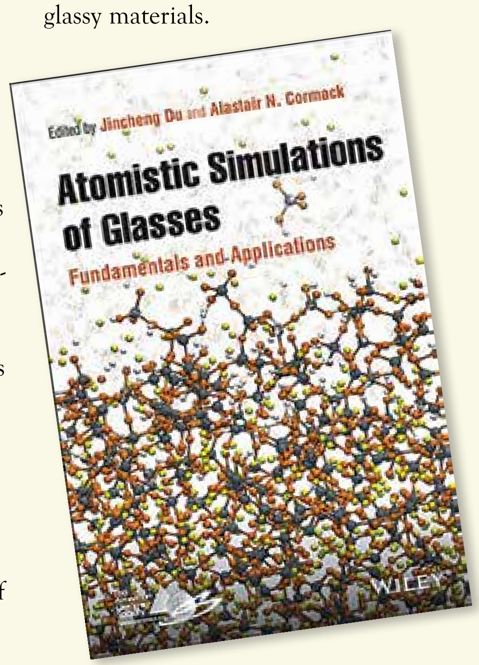
John C. Mauro
Guest columnist

Review of “Atomistic Simulations of Glasses”

Modeling and simulation are crucial for understanding structure–property relationships in glass-forming systems and for accelerating the design of next-generation glassy materials. *Atomistic Simulations of Glasses* is a comprehensive volume dedicated to the topic of atomic-scale modeling of glassy materials, with particular emphasis on silicate glasses of practical industrial interest. As such, this book fills a critical gap in the literature, offering an excellent introduction for newcomers to atomistic modeling, as well as a comprehensive and state-of-the-art reference for practitioners in the field.

Atomistic Simulations of Glasses, published by ACerS-Wiley, consists of 15 chapters written by experts from around the world. It is edited by two leading authorities in computational glass science: Jincheng Du (University of North Texas) and Alastair N. Cormack (Alfred University). The book itself is gorgeous, printed in full color on high-quality paper. It is designed in a reader-friendly format, including a comprehensive index, an extensive list of references at the end of each chapter, and a helpful table to decode every acronym used throughout the book. Each chapter is well written and has been carefully polished. The text also flows smoothly across chapters, which is sometimes a problem in edited volumes.

The first five chapters are devoted to fundamentals of atomistic modeling techniques for glassy systems, including classical simulation methods (Chapter 1), quantum mechanical techniques (Chapter 2), reverse Monte Carlo (Chapter 3), structural analysis methods (Chapter 4), and topological constraint theory (Chapter 5). Each of these chapters does a great job at providing both foundational knowledge and discussing the state-of-the-art in methods and tools. The chapter on topological constraint theory is especially interesting because this is a family of techniques developed specifically for glassy materials.



The latter 10 chapters of the book focus on application of these techniques for simulating various glass families of interest. These chapters cover a wide range of silicate, aluminosilicate, and borosilicate glasses, as well as phosphate, fluoride, and oxyfluoride systems. The coverage of transition metal and rare-earth-containing glasses is also a nice touch. There is a particular emphasis on bioactive glasses and glasses for nuclear waste immobilization. As a whole, the 10 application-focused chapters do an excellent job demonstrating the utility and versatility of atomistic simulation approaches for addressing problems of practical concern in the glass science and engineering community. These chapters also provide good perspective on specific needs for future developments in the field.

There are a few missing topics that would have been valuable to include in the book. While reactive force fields are mentioned briefly, an entire chapter devoted to the principles and applications of reactive force fields such as ReaxFF would have been a nice addition, especially because reactive force fields are becoming increasingly important in the glass science community. Also, given the importance of thermal history in governing the structure and properties of glasses, it would have been worthwhile to include a chapter on accessing long time scales, e.g., using kinetic Monte Carlo, metadynamics, or the activation-relaxation technique, all of which have been applied to noncrystalline systems in the literature and can enable simulations to access experimental time scales. It also would have been helpful to expand the chapter on reverse Monte Carlo to include other Monte Carlo techniques more broadly; for example, Metropolis Monte Carlo is a computationally efficient alternative to molecular dynamics for calculating glass structure and static properties. Finally, given the large amount of research activity in modeling of metallic glasses, a chapter on atomistic simulations of metallic glasses would be a nice addition.

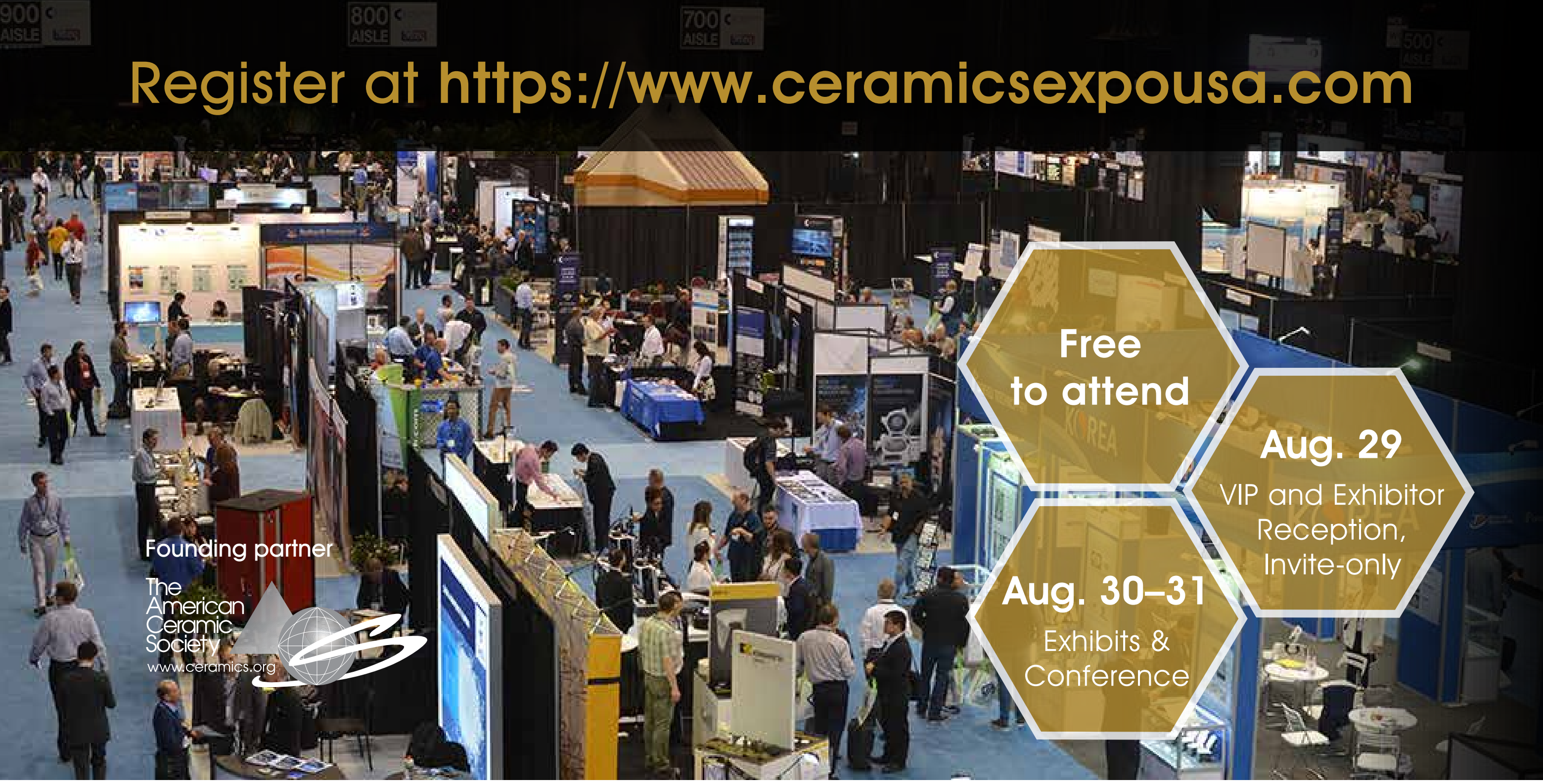
Overall, *Atomistic Simulations of Glasses* is a very welcome addition to the literature and highly recommended for both students and professionals in the field of computational glass science.

Book info

Atomistic Simulations of Glasses, edited by Jincheng Du and Alastair N. Cormack, ACerS-Wiley, 2022. https://bit.ly/3t1Ybae

ACerS members enjoy a 35% discount with the promo code CERAM.

John C. Mauro is a Dorothy Pate Enright Professor in the Department of Materials Science and Engineering at The Pennsylvania State University. ■



ceramics expo

IT'S ALL ABOUT THE INDUSTRY!

Ceramics Expo is the leading event for the advanced ceramics and glass supply chain, bringing together engineers, decision makers, and buyers from the advanced ceramics and glass supply chain and end-user OEMs. It attracts more than 2,000 visitors, 275+ exhibitors, and 30+ leading speakers to its specialist conference stages at The Huntington Convention Center in Cleveland, Ohio. The event is a platform for the industry to share technical expertise in ceramics with real-world case studies, cutting-edge technologies and materials, and the very latest industry trends.

Ceramics Expo, now in its seventh year, provides an unrivaled opportunity to see firsthand and up close the innovations in materials, processes, and products that are driving today's ceramic manufacturing industry.

"This is the largest in-person event for the global ceramics industry in 2022. We're really looking forward to reuniting with our peers, colleagues, friends, and customers face-to-face in August," says Raymond Pietersen, event director at Ceramics Expo.

As the founding partner working with event organizer Smarter Shows, ACerS is delighted to build on the Ceramics Expo tradition. With the United Nations designation of 2022 as the International Year of Glass, this year is especially meaningful for the glass manufacturing sector.

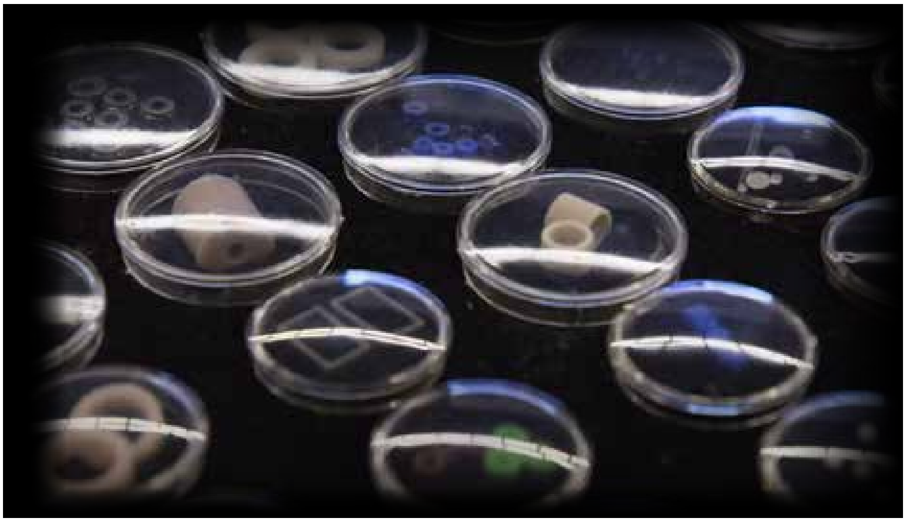
THERMAL MANAGEMENT EXPO – NEW this year

The all-new Thermal Management Expo will run alongside Ceramics Expo. Plan to extend your visit to learn the latest in heating and cooling technologies, systems, and materials.

The Thermal Management Expo Conference will bring together technical experts from across the thermal management supply chain, from thermal management material and system suppliers to end users (and anyone in between!). The one-of-a-kind, free-to-attend conference will address topics applicable to a range of sectors, including automotive, aerospace, energy, telecom, and electronics.

Topics at this year's conference will include

- Insights into thermal management systems and design
- Thermal interface materials
- Innovations in battery cooling
- Electronic thermal management
- Modeling and simulation
- And much more…



al outlooks and applications, energy technologies, additive manufacturing, and more. Speakers include eminent voices from global companies and academia, such as American Elements, GE Aviation, Lockheed Martin, and Corning, among others.

Attendees are invited to stop by Booth 728 to learn how ACerS can benefit you and your company. ACerS Corporate Partnership program offers you and others in your company dozens of opportunities to connect with a global community of ceramic and glass professionals as well as access a wealth of technical and professional development resources for you and your staff.

Join us in August at Ceramics Expo in Cleveland, Ohio. Get all the details and preregister now at https://www.ceramicsexpousa.com. ■

Mark Mecklenborg, ACerS executive director, says, "This is the first time a material has been designated for an International Year, and it points to the many important ways glass—as well as ceramics!—have impacted humanity through millennia, and will continue to do so in the future."

Ceramics Expo offers unparalleled access to the latest materials specifications and capabilities as the supply chain reunites to explore the future of materials development. A pass to the free-to-attend event includes access to the exhibition hall, which displays the innovations and technologies that are changing the future of advanced ceramics and offers the opportunity to meet the entire supply chain under one roof. Exhibitors include Fiven, Imerys, Goodfellow Corp, XJet, GeoCorp, Corning, Harrop Industries, ZEISS, Saint-Gobain and many more key players in the sector, including international representation from Canada, Europe, Korea, and China.

The 2022 conference program theme focuses on manufacturing and industry development. Industry experts tackle the most pressing industry and supply chain challenges by discussing hot topics such as sustainability, industri-

CERAMICS EXPO CONFERENCE AGENDA AT-A-GLANCE

Day 1 – Materials, Manufacturing, and Applications – Tuesday, Aug. 30

9:30 a.m.	Opening Keynote
10:30 a.m.	Panel Discussion: Roadmap to Scale-up Success: Effective Solutions for the Continued Development of Ceramic Matrix Composites
11:20 a.m.	Panel Discussion: Material in Focus: Realizing the Potential of Silicon Carbide for Power Electronics
1:30 p.m.	Ask the Experts: Understanding How the Latest Advancements in Ceramic Additive Manufacturing Can Benefit Your Application
3:00 p.m.	Panel Discussion: Shaping the Future of Energy Storage Through Ceramic Optimization
4:20 p.m.	Presentations: Celebrating the International Year of Glass: The Role of Glass in the Age of Sustainable Development

Day 2 – Industry Development – Wednesday, Aug. 31

9:30 a.m.	Panel Discussion: Staying Ahead of the Curve: Analyzing Outlooks for the Technical Ceramics Market
10:50 a.m.	Panel Discussion: Improving Industry Efficiency Through Collaboration and Innovation
1:00 p.m.	Panel Discussion: Understanding Growth Opportunities and Development Capacities for Lower Middle Market Ceramic Companies
2:20 p.m.	Fireside Chat: Bolstering the Ceramic Workforce for the Continued Development of Material Innovation

Why you should visit Ceramics Expo 2022

- **Source** cutting-edge advanced ceramic materials and technologies from 275+ leading suppliers and manufacturers.
- **Understand** the latest industry developments from 30+ expert speakers and game-changers.
- **Generate** valuable business connections with the Ceramics Expo B2B Matchmaking service.
- **Understand** novel market applications to learn where the requirements for new materials lie.
- **Find** sourcing solutions for manufacturing equipment components without compromising product quality.
- **Locate** new solutions to technology development and implementation, cost reduction, and scaling-up of manufacturing processes.
- **Learn** how to prevent material inconsistencies and defects, such as cracks.
- **Evaluate** use cases of the latest products and services with live demos and showcases.
- **Understand** changing regulations and the impact of these on ceramic technologies and new opportunities.
- **Network** with your peers from across the advanced ceramics value chain, from manufacturers and suppliers to major end-users from the aviation, automotive, energy, medical, and electronics sectors.

UPCOMING DATES

SEPT. 7–9, 2022
Register now!

5TH ENERGY HARVESTING SOCIETY MEETING

ceramics.org/ehs22

HYATT REGENCY BALTIMORE, BALTIMORE, MD.

Energy harvesting has become the key to the future of wireless sensor and actuator networks for variety of applications including monitoring of temperature, strain, humidity, light, and location of persons within buildings, chemical/gas sensor, structural health monitoring, and IoT.

JAN. 17–20, 2023
Submit your abstract

ELECTRONIC MATERIALS AND APPLICATIONS 2023 (EMA 2023)

ceramics.org/ema2023

DOUBLETREE BY HILTON ORLANDO, ORLANDO, FLA.

EMA 2023 is an international conference focused on electroceramic materials and their applications in electronic, electrochemical, electromechanical, magnetic, dielectric, and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society.

JAN. 22–27, 2023
Submit your abstract

47TH INTERNATIONAL CONFERENCE AND EXPO ON ADVANCED CERAMICS AND COMPOSITES (ICACC 2023)

ceramics.org/icacc2023

HILTON DAYTONA BEACH RESORT AND OCEAN CENTER, DAYTONA BEACH, FLA.

The 47th ICACC returns as an in-person conference. The conference will provide a platform for state-of-the-art presentations and information exchange on cutting-edge ceramic and composite technologies.

OCT. 9–12, 2022
Register now!

ACERS 124TH ANNUAL MEETING with MS&T22

MATERIALS SCIENCE & TECHNOLOGY

https://www.matscitech.org/MST22

Organizers: The American Ceramic Society, AIST Association for Iron & Steel Technology, TMS The Minerals, Metals & Materials Society

DAVID L. LAWRENCE CONVENTION CENTER, PITTSBURGH, PA.

NEW this year—The Materials Science and Technology Partnership has engaged the commercial exhibition firm Event Partners to sell and manage the full exhibition at MS&T22. In addition, Event Partners will co-locate two commercial exhibitions run by the company within MS&T22: The Advanced Materials Show and the first-ever Nanotechnology Show.

The Materials Science & Technology technical meeting and exhibition series is a long-standing, recognized forum for fostering technical innovation at the intersection of materials science, engineering, and application. At MS&T, you can learn from those who are on the cutting edge of their disciplines, share your work with the leading minds in your field, and build the valuable cross-disciplinary collaborations unique to this conference series.

JUNE 4–9, 2023
Save the date!

2023 GLASS & OPTICAL MATERIALS DIVISION ANNUAL MEETING (GOMD 2023)

ceramics.org/gomd2023

HOTEL MONTELEONE, NEW ORLEANS, LA.

ACerS Glass & Optical Materials Division will hold its annual meeting in New Orleans, La., from June 4–9, 2023.

Calendar of events

August 2022

28–Sept 1 ➡ 11th International Conference on High Temperature Ceramic Matrix Composites – Ramada Plaza Jeju Hotel, Jeju, Korea; https://www.ht-cmc11.org

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

September 2022

7–9 5th Energy Harvesting Society Meeting – Hyatt Regency Baltimore, Baltimore, Md.; https://ceramics.org/event/5th-energy-harvesting-society-meeting

October 2022

9–12 ACerS 124th Annual Meeting with Materials Science & Technology 2022 – David L. Lawrence Convention Center, Pittsburgh, Pa.; https://ceramics.org/MS&T22

12–13 AM Ceramics 2022 – Fraunhofer IKTS, Winterbergstraße, Dresden, Germany; http://www.am-ceramics.dkg.de

30–Nov 3 7th International Conference on Electrophoretic Deposition – LaFonda on the Plaza, Santa Fe, N.M.; http://engconf.us/conferences/materials-science-including-nanotechnology/electrophoretic-deposition-vii-fundamentals-and-applications

November 2022

6–8 Total Solutions Plus (TPS) – Hyatt Regency, Indian Wells, Calif.; https://www.ctdahome.org/tsp/2022/index.shtml

30–Dec 2 ASEAN Ceramics – IMPACT Forum Hall 4, Bangkok, Thailand; https://aseanceramics.com/thailand/#thai-about

December 2022

7–9 ➡ 7th Highly-functional Ceramic Expo Tokyo – Makuhari Messe, Chiba, Japan; https://www.ceramics-japan.jp/en-gb.html

January 2023

17–20 Electronic Materials and Applications 2023 (EMA 2023) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla; https://ceramics.org/EMA23

22–27 47th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2023) – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla; https://ceramics.org/ICACC23

May 2023

17–19 ➡ 8th Highly-functional Ceramic Expo Osaka – INTEX Osaka, Osaka, Japan; https://www.ceramics-japan.jp/en-gb.html

June 2023

4–9 ACerS Glass & Optical Materials Division Annual Meeting (GOMD 2023) – Hotel Monteleone, New Orleans, La; https://ceramics.org/event/2023-glass-and-optical-materials-division-annual-meeting-gomd-2023

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/event/materials-challenges-in-alternative-renewable-energy-2020-mcare-2022-combined-with-the-6th-annual-energy-harvesting-society-meeting-ehs-2022

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

September 2023

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

July 2024

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

Dates in RED denote new event in this issue.

Entries in BLUE denote ACerS events.

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

denotes International Year of Glass event

denotes virtual meeting

classified advertising

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custom/toll processing services

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firing/melting/drying

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liquidations/used equipment

maintenance/repair services

AD INDEX

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AUGUST 2022

AMERICAN CERAMIC SOCIETY bulletin

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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.

Louis Kirkley
Guest columnist

Unraveling the shifting sands of the glass container shortage

For researchers like me, we took the quick shipping of chemical solvents for granted. But supply chain became a staple of office talk as we progressed through the pandemic and shipments that usually took only a week or two stretched into months-long waits.

As of summer 2022, the topic has not gone anywhere. If anything, shortage discussions are more abundant in newsfeeds and social media as journalists and the public try to make sense of the supply chain crisis that began with COVID-19.

Regarding solvents, the delay in this supply chain traces in part to a shortage of the glass containers in which they are shipped. However, the reason for the glass container shortage is sometimes misattributed online.

In 2019, the United Nations Environment Programme released a report raising awareness of the finite supply of sand and explaining how effective policy, planning, regulation, and management is needed to meet worldwide demand while avoiding overextraction and depletion.[1] As a result, some people believe the current glass container shortage is due to a shortage of sand. However, while a sand shortage in some parts of the world may be the root cause for certain other shortages, such as in concrete and construction applications, it is not the case for the current glass container shortage in North America.

The North America-based Glass Packaging Institute (GPI) sought to clarify this misconception in a news release.[2] "Silica sand appropriate for remelting in glass furnaces needs to meet detailed industry specifications and is not found in beach or riverbed areas, but in specific mineral deposits with proven multi-year reserves," they explain.

Currently, there are more silica sand reserves available in North America than demand from container and other end market destinations. The recent lack of domestically available glass bottles and jars is instead a result of supply chain and tariff policies, GPI clarifies.

In a recent op-ed,[3] Scott DeFife, president of GPI, points out that nearly all recent accounts citing a dire "glass shortage" were connected to a specific anecdote related to imported filled or unfilled bottles. "North American raw materials supply is strong and glass producers … are capable and continue to meet consumer demand," he says.

A truck transports silica sand from a quarry that meets the specifications for fracking.

It is comforting to consider that delays should lessen once the world's supply chain recovers from the pandemic-fueled backlog. However, while consumers should be careful to not equate glass container shortages with the sand supply itself, it is important for suppliers to avoid being tempted by a similar fallacy: that a strong sand supply chain now necessarily equates to a strong supply chain later.

A challenge to this mistaken belief already looms in the form of an aging labor force. U.S. Bureau of Labor Statistics report that for 2021, there are 717,000 workers aged 55 and over in mineral mining and rail/truck transportation as opposed to 138,000 aged 16–24.[4] This skewed ratio poses a significant bottleneck down the decade if issues surrounding labor recruitment, retention, and automation are not sufficiently addressed.

Tension already is felt by some in the fracking industry, which also relies on high-purity sand. One fracking company reports they cannot get enough sand, claiming "fewer people have been working in the mines and there has been a shortage of truck drivers."[5]

Even if the North American sand supply chain is robust to import-related delays, future innovations in sand-dependent industries, whether domestic or overseas, could cause large demand shifts. I hope high-purity sand mining companies take the supply chain lessons from the pandemic to heart and are agile to these future stresses. Or, perhaps, the luxury of rapid shipping was another unsustainable fallacy exposed by the pandemic.

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Louis Kirkley is a graduate student in the Department of Materials Science and Engineering at The Pennsylvania State University, where he focuses on sustainable organic electronics. In his free time, he enjoys long-distance cycling and writing short stories.

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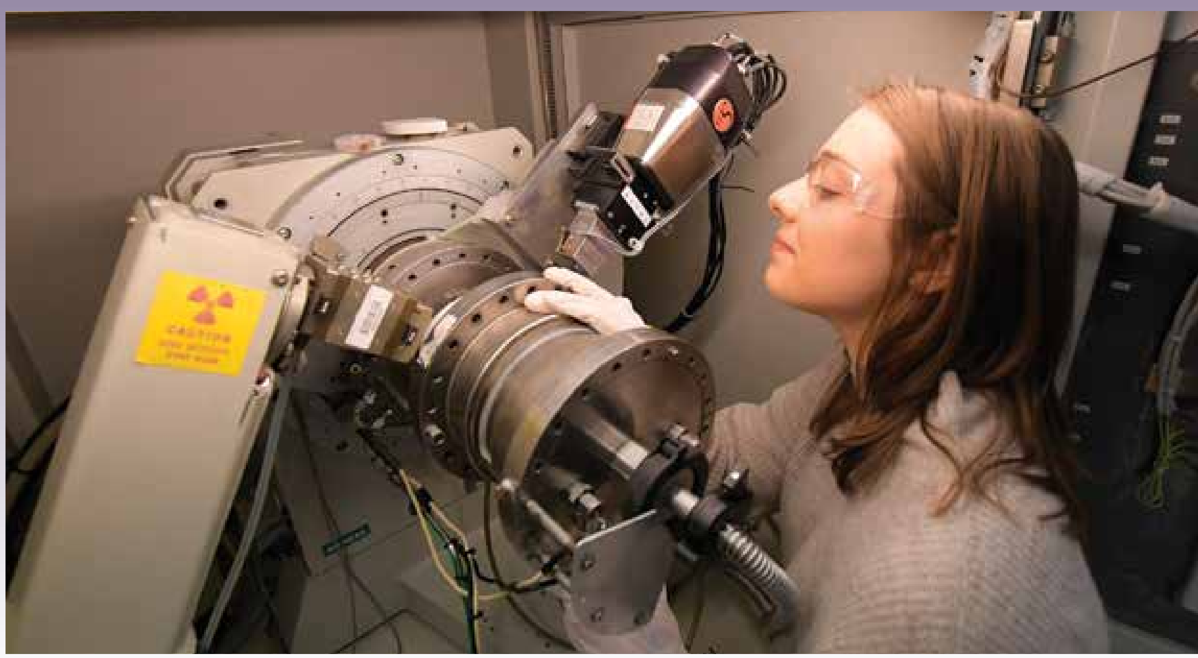

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