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Graphite purification:

**Challenges,
technologies, and
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Graphite purification: Challenges, technologies, and future directions

Technical and regulatory challenges of modern graphite production will require innovations to support the resilience and sustainability of the global graphite supply chain.

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Correction: The incorrect employment information was provided for Dileep Singh's president-elect announcement in the June/July 2026 *Bulletin*. The correct information appears in the online PDF at <https://bulletin.ceramics.org>.

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Strategic silica: A century of sourcing this modern critical resource

High-purity silica is a core component of many modern advanced technologies. This CTT focuses on three relatively recent technological evolutions enabled by this globally scarce resource and looks at the challenges with sourcing the raw material.

Read more at <https://ceramics.org/strategic-silica>

Also see our ACerS journals...

Energy-efficient combustion technologies and burner designs for glass melting furnaces

By N. Sadoughipour, S.-P. Bortey, et al.

International Journal of Applied Glass Science

Structure-informed design of float-compatible thin glass supported by data-driven screening

By Y.A. Gösterişlioğlu, B. Arslan, et al.

Journal of the American Ceramic Society

ZnO-functionalized silicon carbide ceramic membranes for removing impurities from biodiesel

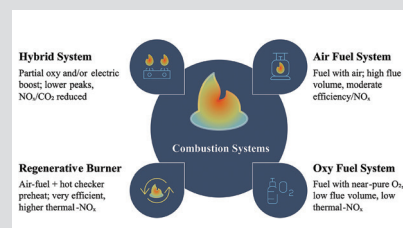
By A.S. Romero, N. Santra, et al.

International Journal of Ceramic Engineering & Science

Discovered method for scalable, eco-friendly, and low-waste extraction of TiO₂ nanoparticles from ilmenite (FeTiO₃)

By M.-H. Park, Y.-K. Hong, et al.

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Credit: Sadoughipour et al., IJAGS



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ACSBA7, Vol. 105, No. 6, pp. 1–44. All feature articles are covered in Current Contents.

Artificial intelligence is reshaping glass understanding and design

To the ceramics and glass community,

For centuries, the development of glass relied on costly, slow trial-and-error experiments guided by chemical intuition and accumulated industrial know-how. This paradigm is now changing because modern high-throughput computation and machine learning (ML) algorithms can uncover hidden potential in a short amount of time.

A stimulus for this transition was Zanotto and Coutinho's 2004 paper, "How many non-crystalline solids can be made from all the elements of the periodic table?"¹ That work highlighted the astronomical number of possible glass compositions (more than 10^{52}) compared to the infinitesimal fraction already synthesized and experimentally characterized (about 10^6). The implication was that conventional experimental approaches alone cannot efficiently explore the enormous "glass genome," thus motivating the use of data-driven discovery strategies.

In the two decades since that paper, various groups often led by ACerS members Anoop Krishnan, John Mauro, and Morten Smedskjaer have published dozens of articles harnessing machine learning for glass science and development. I will highlight just a few studies from my own group and collaborations to demonstrate the types of developments taking place.

The 2018 paper by Cassar et al. used an enormous dataset (55,000 data points) to demonstrate that ML models could predict glass transition temperature with remarkable accuracy across highly diverse oxide systems.² It also showed that large databases, such as SciGlass and INTERGLAD, could serve as training grounds for predictive materials informatics.

Subsequent studies expanded this framework to many other properties, including density, elastic modulus, refractive index, and Young's modulus. Then in 2021, a paper by Zanotto et al. demonstrated how ML can both predict and interpret several oxide glass properties using large datasets.³ Importantly, the authors emphasized that ML should not be treated merely as a "black box." Modern interpretability methods, such as SHAP analysis and feature importance analysis, can help researchers identify which compositions most strongly influence specific properties and (perhaps) even why.

Early ML studies focused primarily on predictive power and accuracy, but recent works increasingly incorporate chemical and structural knowledge into the models themselves. A striking example is the 2023 paper by Mannan et al., which employed ML informed by physically interpretable descriptors to connect both composition and load effects to glass hardness.⁴

Recently, the focus of studies has shifted from property prediction to inverse design, i.e., using a targeted combination of properties to guide the creation of new glass compositions. This

shift transitions ML from a passive analytical tool to an active materials-design engine. For example, Cassar et al. coupled ML models with genetic algorithms to design optical glasses optimized for both refractive index and glass transition temperature,⁵ while Souza et al. used ML-assisted design to develop lead-free niobium crystal glasses with improved optical properties.⁶

For young researchers entering the field, several lessons emerge clearly. First, high-quality datasets and data science skills are now as valuable as sophisticated laboratory equipment and know-how. Second, ML does not replace the fundamentals of glass science; rather, it requires researchers to combine expertise in both glass science and computational methods. Third, improved ML algorithms and enlarged, curated datasets offer enormous opportunities to accelerate the discovery of glasses for every application imaginable, from healthcare and energy to communications and quantum technologies.

Despite impressive progress, there remains several challenges: the scarcity of reliable datasets for many properties, biases introduced by uneven experimental coverage and errors, limited treatment of processing history, and the difficulty of extrapolating beyond known compositional domains. Overcoming these challenges will require collaborative efforts among experimentalists, computational scientists, statisticians, and ML specialists.

The convergence of glass science and ML is still in its early stages, but it is already reshaping how researchers understand, predict, and design disordered materials.

Sincerely,

Edgar D. Zanotto (Senior professor, Federal University of São Carlos)

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Predictive power: Rare-earth-bearing rock formation mapped to variations in Earth's outer layer

The development of advanced electronics (1960s–1990s) followed by the push for renewable energy technologies (2000s–present) have made rare earth elements the “gold rush” of the 21st century. However, the uneven geographic distribution of global rare earth reserves has made securing a steady supply of rare earths difficult for many governments around the world.

Finding new rare earth deposits requires prospectors to assess the regional geology and determine if it matches the environment typically expected to host rare earths. Many of these explorations focus on sites or regions already known to host other deposits, but having a stron-

ger general understanding of what factors lead to rare earth formation might allow prospectors to conduct searches on a global scale.

In a recent open-access paper, four researchers from the University of Cambridge aimed to map the relationship between the Earth's outermost layer, called the lithosphere, and the global distribution of carbon dioxide-rich magmas, which are important hosts of rare earth deposits.

The researchers note that previous studies have observed some relationships between lithosphere thickness and magma occurrence. However, “estimates of lithospheric thickness associated with

these magma types derive from varying inversions of seismic data, thus rendering direct comparisons of lithospheric thickness among these magma types unreliable,” they write.

To enable a quantitative understanding of these relationships, the researchers assembled chemical data on 9,000 igneous rock samples from around the world and then plotted the data on a map alongside detailed information about the Earth's interior. This approach allowed them to “show how the thickness of the lithosphere determines the generation of the full spectrum of carbonated (<5 to >25 wt.% CO₂) magmas,” they write.

In general, they found that CO₂-rich magmas occur along the steep edges of Earth's thickest and oldest lithosphere. These thicker parts keep the underlying mantle rocks at high pressures and relatively cool, so only a small amount of the mantle can melt into magma. The magma then tends to get stuck at the base of the lithosphere, where it solidifies into CO₂-rich igneous rocks.

However, “it's only when those rocks are re-melted later that the metals get a second stewing—becoming concentrated enough to form a useful ore deposit,” a University of Cambridge press release on the study explains.

These findings provide “predictive power for the emplacement locations of exotic CO₂-rich magmas and, by inference, their associated economic deposits,” the researchers write. They now intend to extend their map to include rocks older than 200 million years old, “which host most of the economic rare earth element deposits and mines globally,” the press release explains.

The open-access paper, published in *Nature Geoscience*, is “The global distribution of CO₂-rich magmas is determined by lithospheric thickness” (DOI: 10.1038/s41561-026-01990-7). ■



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Corporate Partner news

Eirich wins 2026 German Innovation Award

Maschinenfabrik Gustav Eirich GmbH & Co. KG received the German Innovation Award 2026 in the "Excellence in Business to Business—Machines & Engineering" category. Eirich was recognized for its MixSolver machine, which helps create slips and slurries.

Read more: <https://www.eirichusa.com/en/news-2>

Nexceris launches 'Lab to Launch' platform to speed clean energy commercialization

Ohio-based Nexceris announced the launch of a new Lab to Launch platform, which is designed to help accelerate the commercialization of advanced energy technologies. The platform reflects Nexceris' transition from a materials and components supplier to a full-service strategic development partner in clean fuels, hydrogen, and electrification.

Read more: <https://nexceris.com/newsroom>

Orbray partners with three companies on joint project to recycle zirconia dental waste

Tokyo-based Orbray Co., Ltd. partnered with Shofu Inc. (Kyoto), Tosoh Corporation (Tokyo), and Mitsui Chemicals Inc. (Tokyo) on a joint project to recycle zirconia dental waste with practical application targeted for 2028.

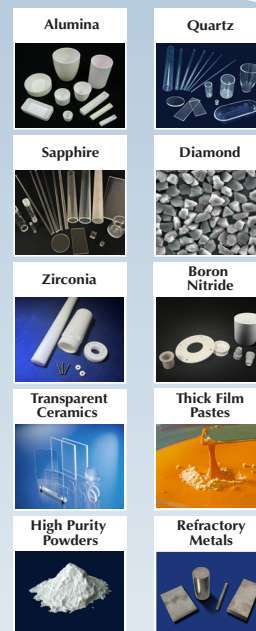
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Resilient glass manufacturing: Solutions to supply chain challenges

The past few years have brought numerous challenges for ceramic and glass manufacturers, from spiking energy prices and raw material scarcity to growing concerns about the sector's environmental impacts. Various methods of addressing these concerns are being investigated, including using alternative raw materials, lowering the energy usage and carbon emissions of glass melting, and introducing more recycled material into the manufacturing process.

In the article "Soda ash free batches for novel container glass compositions,"¹ Engelmann, Conradt, and Roos aimed to tackle the carbon emissions in glass manufacturing that come from the carbonate batch materials, specifically by eliminating sodium carbonate (soda ash) from the batch. Eliminating soda ash would significantly reduce the carbon footprint, but soda-lime-silica glass (SLS) typically requires a source of Na_2O to achieve lower melting temperatures. The authors suggest that recycled cullet from conventional SLS glass can be used in the batch to provide a source of Na_2O , as well as reduce the amount needed of some other batch materials and provide a partial solution to sourcing new batch materials.

Engelmann et al. tested four different glass compositions with varying amounts of Na_2O levels in the recycled container glass cullet, between 2.00 to 10.00 mass% (Figure 1). All compositions were compared against two slightly different standard versions of SLS in terms of viscosity, thermal expansion, hydrolytic resistance, electrical conductivity, and the calculated liquidus temperature. The authors discussed the energy requirements of each composition, and their results indicated that compositions close to 10 mass% Na_2O may be the best place to start for industrial-scale trials.

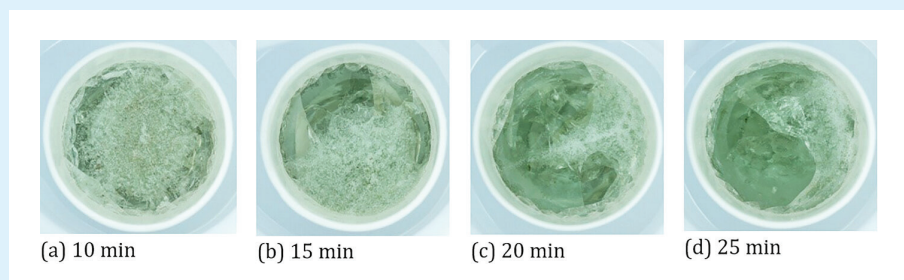


Figure 1. Picture of the batch blanket (floating layer of unmolten raw materials) derived from composition S60-N5. The batch contains 5.00 mass% Na_2O .

Another way to reduce general energy consumption is by developing insulating materials with lower thermal conductivities to decrease heat loss in buildings. Glass foams have been investigated as cost-effective and sustainable thermal insulation. These foams can be sintered from recycled glass particles when combined with a foaming agent, creating pores within the material structure when gases are released. Other waste products, such as sludge from marble cutting processes and eggshells, have been used as foaming agents as well.

Silica-rich additives are often included to increase chemical compatibility with the waste foaming agents. For example, rice husk ash has been explored in previous studies, as it is an often-underutilized agricultural byproduct.

In the article "Sustainable glass foams from recycled glass and rice husk ash: Thermal insulation performance for ceiling applications,"² Bertolo et al. studied the production of sustainable glass foams combining many of the alternative raw materials mentioned above. They used recycled glass as the primary raw material, rice husk ash as the silica-rich additive, and calcium carbonate as the foaming agent to create four different foam compositions. After synthesis, they characterized the foams' morphology, bulk density, and axial compressive strength and then tested the thermal insulation capacity of each composition. This testing was done by fabricating large foam boards and

installing them as a lining for a reduced-scale ceiling, which was compared to the same structure without any insulation.

Based on the characterization analyses and thermal insulating testing, the authors determined that the foam containing 2 mass% calcium carbonate and sintered at $1,000^\circ\text{C}$ exhibited the best foam properties, which include a compressive strength of 0.81 MPa and high porosity of 88.1%. These findings are comparable to current commercial vitreous foams and data reported in literature. During the practical testing, the foam-coated ceiling reduced the heat transfer up to 114% when compared to the uncoated ceiling in the hottest part of the day, demonstrating the feasibility of using this method for real-life applications.

These articles are just two examples of the important research being reported in ACerS journals that address challenges with the ceramic and glass supply chains. Visit the ACerS journals homepage at <https://ceramics.onlinelibrary.wiley.com> to read more.

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Markets for electricity and hydrogen energy storage

The growing renewable energy market drives demand for improved and novel methods of large-scale energy storage.

Energy storage systems help prevent grid shutdowns by storing and then returning energy to the grid at more convenient times. Two recent BCC Research reports investigate the global markets for electricity and hydrogen energy storage technologies, respectively.

Grid-scale electricity storage

The global market for grid-scale electricity storage technologies was valued at \$32.1 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 30.0% to reach \$151.2 billion by the end of 2029.

Historically, pumped-storage hydropower was the most used method of grid-scale energy storage. However, it faces challenges in certain geographic conditions, so batteries are now preferred because they can be deployed anywhere.

Lithium-ion batteries are the industry standard due to their desirable cycle life-to-cost ratio. However, the limited supply of lithium has allowed several other battery technologies to emerge.

- **Lead-acid batteries:** These batteries consist of a positive electrode containing lead dioxide and a negative electrode containing spongy lead. Despite their lower energy density, lead-acid batteries are more affordable than lithium-ion batteries and can provide large, steady power surges as needed.
- **Flow batteries:** These batteries use liquids to store and discharge energy. Although they are more expensive and have a lower energy density than lithium-ion batteries, their long-term charge retention makes them an attractive option in renewable energy networks.

- **Sodium-ion batteries:** These batteries represent a more affordable alternative to lithium-ion batteries. Although historically known to have lower energy densities, recent advances have improved their performance, making them viable for renewable energy storage.

- **Other batteries:** Solid-state batteries are promising because they use solid rather than liquid electrolytes, which offer the advantages of higher lifetimes, safety, and energy density.

China, the European Union, and the United States combined accounted for around 90% of the grid-scale electricity storage capacity added in 2023. However, the Asia-Pacific region still has the largest market share overall (46.9% in 2023), and it is expected to grow at the highest CAGR due to increasing investments in renewable energy and industrial demand.

Global hydrogen energy storage

The global market for hydrogen energy storage was valued at \$1.0 billion in 2023 and is expected to grow at a CAGR of 72.1% to reach \$23.7 billion by the end of 2029.

Hydrogen energy provides a flexible and long-duration energy storage option apart from battery-based systems. Major drivers of the market include the increasing use of electrolyzers for grid stabilization, an increase in renewable energy generation, and the growing uptake of hydrogen for clean transportation. However, several economic and technological factors restrain market growth.

- **High cost of composite storage tanks:** The main cost component for composite storage tanks is carbon fiber, which has a complex production process. Research and development focuses on using alternative materials, such as recycled carbon fiber and biobased composites.
- **Technical challenges:** The main failure of storage tanks is hydrogen embrittlement, which occurs when

hydrogen atoms disperse into the metal's microstructure and weaken the atomic bonds. Also, hydrogen gas is lightweight with low energy density, so improved storage systems are needed to store hydrogen at higher energy densities and smaller sizes.

- **High investment cost in hydrogen infrastructure development:** A typical hydrogen energy network requires a hydrogen production plant, storage and transportation facilities, and refueling stations. Developing robust hydrogen infrastructure is a long-term project that requires collaborative research efforts and investments.

Europe is the second largest contributing region after Asia-Pacific in green hydrogen, owing to strict government policies, regulatory directives to curb carbon emissions, and the significant presence of electrolyzer original equipment manufacturers. The Asia-Pacific market's growth is driven by its large automotive industry and investments in industrial hydrogen applications.

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 ereister@bccresearch.com.

Resources

BCC Publishing Staff, "Grid-scale electricity storage technologies: Global markets," BCC Research Report EGY142C, March 2025. <https://bit.ly/March-2025-grid-scale-electricity>

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industry perspectives

ACerS Learning Center: Bridging the gap between formal education and the plant floor

If you have been in the ceramics and glass field for more than a few years, chances are you already work with materials or processes that were not part of your formal education. From additive manufacturing and novel sintering processes to alternative energy technologies and advanced computer systems, the list of emerging applications is moving faster than any curriculum can keep up with.¹

While some of this missing know-how can be gained from colleagues, the rapidly increasing rate of retirements is pulling decades of institutional knowledge out the door.² The loss of these experts leaves early- and mid-career professionals to take on responsibilities well beyond their original training.

To overcome this gap between formal education and the plant floor, industrial professionals require access to structured, ongoing educational opportunities.³ The American Ceramic Society is well positioned to help close this gap through the ACerS Learning Center, the ceramic and glass community's go-to place for workforce development programs.

The Learning Center provides access to a range of short courses taught by leading experts in the ceramics and glass field, covering everything from the basics of ceramics and glass manufacturing to next-generation processing methods and advanced materials modeling systems. These rigorous and technically grounded courses are built for the ceramics and glass community by the people who are advancing the field, available in both in-person and virtual formats so that geography and travel budgets do not stand in the way of participating.

In addition to working with esteemed ACerS members on these courses, the Society also partners with several other materials organizations to develop specialized offerings. For example, ACerS' long-standing relationship with the

Edward Orton Jr. Ceramic Foundation has led to a robust Refractory Technology Program spanning microstructure, thermal properties, design, and failure analysis of refractory ceramics. In 2024, the Society received government funding to launch a Hypersonic Materials Training Program in partnership with the United States Advanced Ceramics Association. The program subsequently received a two-year extension of funding in 2025 so the training could reach even more professionals in industry, national labs, and government agencies.

In 2025, the highest ever number of participants completed training through the ACerS Learning Center since the program launched in 2020. With more than 20 courses now available through the On-Demand Catalog—and new offerings in development—the Society is making great progress toward the goal of removing every barrier between ceramics and glass professionals and the knowledge they need.

The strength of ACerS has always rested on the expertise and dedication of its members. By investing in workforce development, the Society is not only supporting individual careers but also ensuring the ceramics and glass community stays at the forefront of materials innovation.

If you have not explored ACerS Learning Center, I would encourage you to look through the course offerings at <https://ceramics.org/education>. If there is a topic missing that you would like to see offerings for, let us know—this work is strongest when it is shaped by the people it serves.

About the author

Amanda Engen is director of publications and strategic programs at The American Ceramic Society (Westerville, Ohio). Contact Engen at aengen@ceramics.org.

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*All references verified as of June 16, 2026. ■



ACerS Learning Center

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Bioprospecting offers novel pathway to discovering new mineral deposits

“There’s gold in them there hills!” The famous Gold Rush exclamation may also be true for copper, nickel, cobalt, or rare earths, minerals that in the right hands can be as valuable as gold.

In the Gold Rush days, miners used pickaxes, shovels, and pans to hunt for the glittery substance. Today, mining companies spend billions searching for new mineral deposits, using advanced technological methods such as geological mapping, drilling, satellite imaging, and geophysical surveys. These methods can be extremely effective, but they are also expensive, time-consuming, and can be environmentally disruptive.

One alternative for identifying new mineral deposits being explored by academic researchers and, increasingly, private businesses involves an unlikely and inexpensive partner to assist with exploration: living organisms.

The field known as bioprospecting analyzes the biological and chemical signals left by animals, plants, fungi, and microbes to identify the presence of potential new mineral deposits. It has the potential to reduce exploration costs, improve efficiency, and minimize environmental impact during the early stages of mining development.

Australia has been the site of much work in this area. The continent is anticipated to hold massive undeveloped reserves of critical minerals, but many of the prospective areas are hidden beneath a thick veneer of regolith and sediments, making traditional surface exploration techniques difficult. Bioprospecting offers a way to overcome this challenge, and fortunately, Australia is home to many unique species that can potentially serve as bioprospectors.

For example, digging mammals such as bettongs and bandicoots will disrupt the topsoil in their search for food and shelter, exposing the material hidden

underneath. Research has found these excavation activities help improve microbial activity and potassium levels,¹ which is good for soil health and thus seed growth, but they typically do not dig deep enough to bring up evidence of deep-seated ore deposits.

Instead, subterranean termites can dig much deeper than mammals and bring up traces of minerals from far below the ground. These traces could potentially serve as signposts for hidden mineral deposits, according to researchers from Australia’s national science agency.²

As a real-world example, one gold deposit in Western Australia has been mined for more than 100 years, but finding gold there remains difficult because it is often hidden beneath a layer of eroded material. In 2012, researchers studied termite mounds in a known gold-rich area of the deposit and found the nests contained high concentrations of gold, with levels five to six times higher than concentrations found just a few yards away.³

However, rather than mammals or insects, microbes appear to show the most promise for discovering what lies beneath the ground. Microbes exist everywhere, rather than animal prospectors that only live in certain areas. Furthermore, they often evolve in direct response to the buried minerals. So, researchers can test the microbe’s metabolic activity and DNA for clues rather than relying on trace minerals that digging creatures may or may not have brought to the surface.

As an example of microbes’ potential, researchers at the University of British Columbia identified buried copper ore by testing the DNA of microbes in the surface soil.⁴ First, within a laboratory setting, they introduced copper to soil microbes from two copper-rich areas in Canada and then used DNA sequencing to see how the microbes changed. They



Credit: Endolith

Figure 1. Endolith founder and CEO Liz Dennett holds up an example of the company’s tailored microbial colony in an acid solution.

used this information to establish a biological fingerprint that could be used to indicate the presence of copper, a mineral essential for clean energy technologies and electric vehicles.

The potential of microbes to serve as beacons for valuable ore has attracted serious business investment. Mining giant Rio Tinto, based in London with major operations in Australia, developed what it calls the world’s largest database of mine site microbial data. Working with government; not-for-profit research partners; and mining, bioinformatics, and synthetic biology companies, Rio Tinto created the Mining Microbiome Analytics Platform (M-MAP).⁵ Using more than 2,500 rock, water, soil and tailings samples from its own mines as well as samples from another company’s sites, the database provides detailed insight into the microbiomes there as well as to those sites’ geospatial, climate, and chemical data.

The company says it anticipates using microbes not only for more sustainable resource extraction, but it expects that microbes potentially could be used to

remove waste metals from sites, speed reforestation after a mine closes, or treat contaminated water. This alternative application showed so much potential that it was spun off into an independent biotechnology company called nPhyla, which will develop advanced microbial solutions for the mining lifecycle from exploration and operations to closure and remediation.

Endolith is a Colorado-based industrial biotech startup that “breeds and deploys microbe colonies” to extract copper and other critical minerals from low-grade ore (Figure 1).⁶ In 2025, the company announced the results of tests that it said found its bioengineering processes outperformed conventional approaches to gleaning copper from waste once considered infeasible to process. That, as well as its partnership with Melbourne, Australia-based mining giant BHP, led to a round of venture funding totaling \$13.5 million.

“This [project] demonstrates what’s possible when the world’s oldest miners [microbes] go to work on one of today’s biggest challenges,” says Liz Dennett, founder and CEO of Endolith, in a press release.⁷

As researchers continue to explore the possibilities of microbes to function as early indicators for hidden mineral resources, combining this approach with advanced technologies such as artificial intelligence and DNA analysis will enable a new generation of cost-effective, non-invasive commercial exploration systems.

About the author

David Holthaus is an award-winning journalist based in Cincinnati, Ohio, who covers business and technology. Contact Holthaus at dholthaus@ceramics.org.

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⁴B.P. Iulianella Phillips et al., “Microbial indicators and detection of Cu-sulfide ore mineralization,” *Geology* 2025, **53**(9): 763–768.

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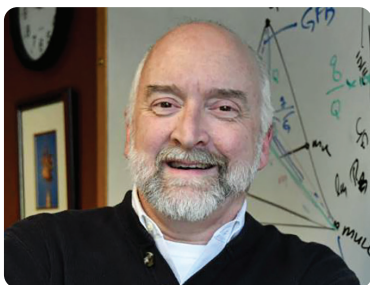
⁷D. Corrington, “Endolith achieves breakthrough in critical mineral extraction,” *Reuters*. Published 13 May 2025. <https://bit.ly/4vFr4Hg>

*All references verified as of June 16, 2026. ■

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SOCIETY DIVISION SECTION CHAPTER NEWS



Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners: ATL, Beralmar Energies, GRANIT Abrasive, and ROMCO Alumina (Sapphire Corporate Partner).



To learn about the benefits of ACerS Corporate Partnership, contact Yolanda Natividad, associate director of membership and industry relations, at (614) 794-5827 or ynatividad@ceramics.org. ■

ACerS New Jersey/Metro New York/Philadelphia Section holds annual event

On April 10, 2026, the ACerS New Jersey/Metro New York/Philadelphia Section held its annual Malcolm G. McLaren Symposium in conjunction with the Department of Materials Science and Engineering at Rutgers, The State University of New Jersey and the Ceramic Association of New Jersey. The theme of the symposium was “Entropy—The Secret Sauce in Materials Engineering.”

This annual event recognizes a distinguished member of the ceramics community as the Malcolm G. McLaren Distinguished Lecturer. This year’s awardee was Helen Chan, professor of materials science and engineering at Lehigh University. Chan’s lecture was titled “Novel processing of entropy-stabilized and compositionally complex materials.” ■



Rutgers Professor Richard Lehman (right) presents Helen Chan with the 2026 Malcolm G. McLaren Distinguished Lecturer plaque.

ACerS International Italy Chapter members enjoy workshop on the multifaceted world of glass

On May 14–15, 2026, the Abate Zanetti Institute hosted the workshop “Le Mille Vite del Vetro—Bringing Glass Back Home!” The workshop was organized with the support of several academic and industrial partners, including the ACerS International Italy Chapter, Polytechnic University of Turin, Ca’ Foscari University of Venice, the Italian Ceramic Society, KMM-VIN, and stakeholders from the glass industry (GIMAV and Glass Company). The event provided a platform for discussing advanced glass materials, sustainable technologies, and the future of glass science while reconnecting these developments with the historical roots of Murano craftsmanship. ■

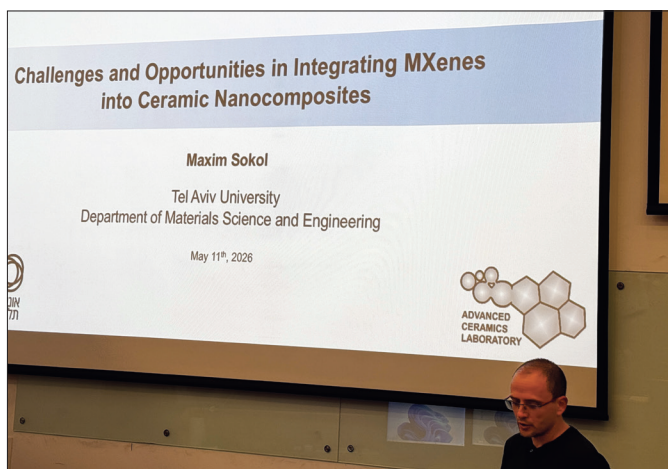


The workshop included a keynote lecture delivered by ACerS President Mario Affatigato (front row, second from left).

FOR MORE
INFORMATION:
ceramics.org/spotlight

ACerS International Israel Chapter holds inaugural event

On May 11, 2026, the ACerS International Israel Chapter held its first workshop. Nearly 100 attendees representing several universities and many industries attended the workshop, which included six invited speakers, a panel discussion titled “Ceramics for Extreme Conditions,” and a poster session. The students who participated in the poster session received a complimentary Graduate and Doctoral Student membership on behalf of the Chapter. ■



Professor Maxim Sokol of Tel Aviv University presented a lecture on MXenes during the first ACerS International Israel Chapter event.



WEBINAR LIBRARY



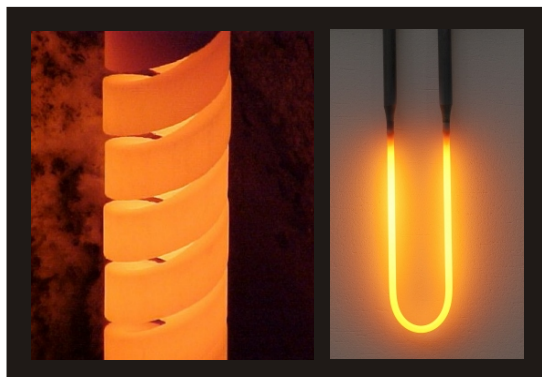
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Original air date: March 20, 2026
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 Featured speaker: Sarah Grabowski

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MEMBER HIGHLIGHTS



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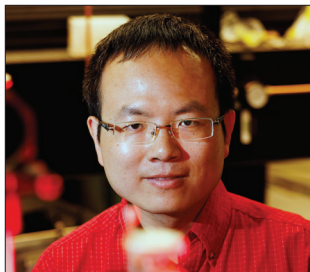
If you will be at least 65 years old by Dec. 31, 2026, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Vicki Evans at vevans@ceramics.org.

FOR MORE INFORMATION:

ceramics.org/membership

Volunteer Spotlight: Bai Cui and Dong (Lilly) Liu

ACerS Volunteer Spotlight profiles members who demonstrate outstanding service to the Society.

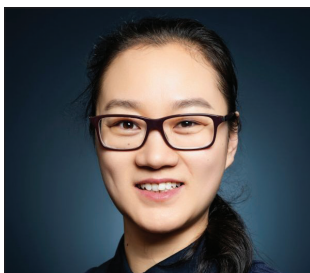


Bai Cui is professor of mechanical and materials engineering at the University of Nebraska-Lincoln. He received his Ph.D. in materials science and engineering from Imperial College London and later conducted postdoctoral research at the University of Illinois Urbana-Champaign.

Cui's research centers on compositionally complex ceramics, ultrahigh-temperature ceramics, irradiation-resistant materials, and advanced laser-based manufacturing technologies. In addition to

research, Cui is passionate about mentoring students, building collaborations across academia and industry, and supporting the growth of the ceramics and manufacturing communities through professional service and volunteer leadership.

Cui has been deeply involved in the Manufacturing Division and currently serves as Division chair. He has organized numerous symposia and technical sessions at ACerS meetings, particularly in the areas of advanced manufacturing, ultrahigh-temperature ceramics, and compositionally complex ceramics. He also contributed to expanding the visibility and influence of the Manufacturing Division by helping position it among the six founding Divisions of ACerS Spring Meeting, which took place for the first time in April 2026. His contributions to the ceramics community have been recognized through honors including the Global Ambassador Award, the Global Star Award from the Engineering Ceramics Division, and the Outstanding Associate Editor Award from *Journal of the American Ceramic Society*.



Dong (Lilly) Liu is associate professor of engineering science and Tutorial Fellow in Trinity College at the University of Oxford. She is also head of the Experimental Mechanics of Advanced Materials group and deputy director of the Rolls-Royce University Technology Center of Solid Mechanics. Liu received her Ph.D. in mechanical engineering from the University of Bristol. After graduation, she served as a research fellow at the University of Oxford and then associate professor at the University of Bristol before returning to Oxford in 2024.

Liu's research focuses on advanced ceramics and alloys in nuclear fission, fusion, aerospace, and the power electronics and radio frequency areas. By developing multiple length-scale approaches combined with novel experimental techniques, her group investigates the deformation and fracture of those materials under extreme service conditions to underpin their safe applications and to enable innovative materials designs. Besides research, Liu serves on several international technical committees, including the FAA Composite Materials Handbook Standards (CMH-17) Ceramic Matrix Testing Working Group and the IOM3 Ceramic Science Committee.

Liu currently serves as secretary of the Engineering Ceramics Division, leading chair of the ACerS International United Kingdom Chapter, chair of the Awards Committee, and chair of the Registration Waiver and Travel Grant Program. She has led and co-led the organization of many symposia at various ACerS conferences over the past five-plus years. Recently, she served as organizing chair and on the International Advisory Board for the HTCMC conference in June 2026. She has been awarded the Global Jubilee Excellence Award and Global Ambassador Award for her research achievements and contributions to the international ceramics community.

We extend our deep appreciation to Cui and Liu for their service to our Society! ■

ACerStudent Engagement: CWRU students bring materials science to Cedar Point

Rishabh Kundu, ACerS Global Ambassador and second-year Ph.D. student at Case Western Reserve University (CWRU) in Cleveland, Ohio, led a STEM outreach initiative during the Physics, Science, and Math Days at amusement park Cedar Point (Sandusky, Ohio) on May 14, 2026. He and other student volunteers from CWRU's Department of Materials Science and Engineering and Department of Macromolecular Science and Engineering collaborated to engage students and families through interactive demonstrations focused on materials science concepts.

The event featured demonstrations using materials science and glass science kits from the Ceramic and Glass Industry Foundation, among other educational resources, alongside interactive activities including creating slime, exploring the behavior of shape memory alloys, and showcasing everyday materials science applications.

"We were delighted by the enthusiasm of the young audience, and the optical fiber demonstration was a special attraction. Many kids could not believe that the same technology leads to super-fast internet," says Kundu.

He adds, "We are happy that we could instill the importance of materials science in some youngsters while exposing others to the field for the very first time. We look forward to revisiting this event again in the future."

All students can gain valuable skills and experiences like Kundu through ACerS student membership. Learn more at <https://ceramics.org/membership/join>. ■



Credit: Isabella M. Giannattasi

Rishabh Kundu, far left, and all the student volunteers from CWRU who traveled to Cedar Point for a STEM outreach initiative during the amusement park's Physics, Science, and Math Days.

Ceramic Tech Chat: Ruyan Guo

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.

Cross collaborations for multifunctional electronics: Ruyan Guo



In the May 2026 episode of Ceramic Tech Chat, Ruyan Guo, the Robert E. Clarke Endowed Professor of Electrical and Computer Engineering at the University of Texas at San Antonio, talks about her research projects, describes how she helped launch an interdisciplinary graduate program at UT San Antonio, and shares about her time serving as a National Science Foundation program director.

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

Names in the News

Members—Would you like to be included in the Bulletin's Names in the News? Please send a current head shot along with the link to the article to mmartin@ceramics.org.



Pelagia-Irene (Perena) Gouma, FACerS, Edward Orton Jr. Chair in Ceramic Engineering at The Ohio State University, was named the 2026 Humboldt Research Award recipient by the German Alexander von Humboldt Foundation. She will begin her research in October 2026 at the Universität Bayreuth in Germany, with two subsequent visits in 2027. She will collaborate with Professor Ralf Moos on the synthesis and properties of functional materials. ■



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AWARDS AND DEADLINES



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AWARDEES AT REFRACTORIES SYMPOSIUM AND SPRING MEETING 2026

Recipients of several Division awards were recognized at the 61st Annual Symposium on Refractories and Spring Meeting 2026. Congratulations to all the awardees! (Recaps on pages 39–41.)

Basic Science Division

Robert B. Sosman



Jon-Paul Maria,
The Pennsylvania
State University

Manufacturing Division

John E. Marquis



Hong Li,
Nippon Electric
Glass, N.C.

Refractory Ceramics Division

Theodore J. Planje



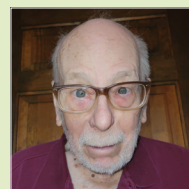
Tomas Richter,
MaterialsPro
Technologies LLC,
Pa.

Glass & Optical Materials Division

L. David Pye Glass Hall of Fame



Lisa Klein,
Rutgers, The State
University of New Jersey



James E. Shelby,
New York State College
of Ceramics at Alfred
University, N.Y.

Varshneya-Mauro-Jain Guru-Chela Travel Fund



Jincheng Du,
University of
North Texas



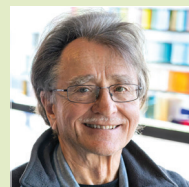
Cristina Lopez Puga,
University of
North Texas

Varshneya Frontiers of
Glass Technology



Timothy Gross,
Corning Inc., N.Y.

Stookey Lecture of
Discovery



Daniel Schwoerer,
Bullseye Glass Co., Ore.

George W. Morey



Sabyasachi Sen,
University of
California, Davis

Norbert J. Kreidl



**Cosmin-Constantin
Popescu,**
2 Pi Inc., Mass.

GOMD student posters

Graduate

First place: "Photon correlation spectroscopy in alkali-germanate glass melts" –**Daniel Olabode**, Creighton University, Neb.

Second place: "Matrix particle size and lead volatilization effects on templated grain growth of $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-PbTiO}_3$ " –**Brooke Downing**, Colorado School of Mines

Third place: "Operando UV-Vis reflectance spectroscopy for fuel cell electrode degradation: A feasibility study" –**Christopher Martin**, Colorado School of Mines

Undergraduate

First place: "Synthesis and analysis of metal-doped nanoparticles for glass additive manufacturing" –**Mariah Varguez**, Creighton University, Neb.

Second place: "Modifying germania and germania-silica nanoparticle chemistry via polyol addition" –**Maggie Schaefer**, Creighton University, Neb.

Third place: "Identifying the effects of structural disproportionation on the physical and electrochemical properties of $\text{Li}_2\text{S-SiS}_2$ glasses" –**Hannah Cochran**, Iowa State University

EDiv student posters

First place: "Direct visualization of sacrificial layer dissolution in free-standing membrane release using Cryo-ToF-SIMS" –**Hsin-Mei Kao**, Oregon State University

Second place: "Characterizing the effect of sodium concentration in $\text{NaSiCON}(\text{Na}_{1+x}\text{Zr}_2\text{Si}_x\text{P}_{3-x}\text{O}_{12})$: 36 mS/cm bulk conductivity achieved at $x = 2.6, 2.8$ " –**Cathy Wang**, University of California, Santa Barbara

Third place: "Reduction of atomically flat epitaxial WO_3 thin films to conducting WO_{3-x} suboxide phases" –**Joshua Feldon**, Northwestern University, Ill.

EDiv oral presentations

First place: "Exploring the structural and functional properties of a novel category of hybrid double metal halide perovskites" –**Kanika Parashar**, The University of Oklahoma

Second place: "Linking structure and property in compositionally complex rare earth zirconates via multimodal probes" –**Keun-Yeol Park**, Seoul National University, Republic of Korea

Third place: "Three-dimensional visualization of dislocations in free-standing BaTiO_3 membranes using multislice electron ptychography" –**Jade Holliman**, The University of Tennessee Knoxville

NEW: Edwin Fuller student posters

This new competition, debuted at ACerS Spring Meeting 2026, celebrates outstanding student research in ceramic and glass science and engineering while honoring the remarkable career and contributions of the late Edwin H. Fuller, an ACerS Distinguished Life Member, past Society president, and respected industry leader.

Graduate

First place: "Direct visualization of sacrificial layer dissolution in free-standing membrane release using Cryo-ToF-SIMS" –**Hsin-Mei Kao**, Oregon State University

Second place: "Characterizing the effect of sodium concentration in $\text{NaSiCON}(\text{Na}_{1+x}\text{Zr}_2\text{Si}_x\text{P}_{3-x}\text{O}_{12})$: 36 mS/cm bulk conductivity achieved at $x = 2.6, 2.8$ " –**Cathy Wang**, University of California, Santa Barbara

Third place: "Photon correlation spectroscopy in alkali-germanate glass melts" –**Daniel Olabode**, Creighton University, Neb.

Undergraduate

First place: "Synthesis and analysis of metal-doped nanoparticles for glass additive manufacturing" –**Mariah Varguez**, Creighton University, Neb.

Second place: "Modifying germania and germania-silica nanoparticle chemistry via polyol addition" –**Maggie Schaefer**, Creighton University, Neb.

Third place: "Reduction of atomically flat epitaxial WO_3 thin films to conducting WO_{3-x} suboxide phases" –**Joshua Feldon**, Northwestern University, Ill. ■

more AWARDS AND DEADLINES

Nomination deadlines for Society awards: Sept. 1, 2026

Contact: Erica Zimmerman | ezimmerman@ceramics.org

Society award	Deadline	Description
Darshana and Arun Varshneya Frontiers of Glass Lectures	September 1	Lectures 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.
Samuel Geijsbeek PACRIM International Award	September 1	Recognizes individuals who are members of the Pacific Rim Conference societies for their contributions to ceramic and glass technology that have resulted in significant industrial and/or academic impact, international advocacy, and visibility of the field. ■

Nomination deadlines for Division awards: Aug. 31 or Sept. 4, 2026

Contact: Vicki Evans | vevans@ceramics.org

Division	Award	Deadline	Contacts	Description
BSD	Graduate Excellence in Materials Science (GEMS)	August 31	Eve Mozur evemozur@mines.edu	Recognizes the outstanding achievements of graduate students in materials science and engineering. The award is open to all graduate students who are giving an oral presentation in any symposium or session at the 2026 Materials Science & Technology meeting.
BSD	Roland B. Snow Award	September 4	Dilpuneet Aidhy daidhy@clemsun.edu	Presented to the Best of Show winner of the Ceramographic Exhibit & Competition, which is an annual poster exhibit to promote the use of microscopy and microanalysis in ceramics research. ■

FOR MORE
INFORMATION:
ceramics.org/awards



Sweet science at COSI: The CGIF returns to the Big Science Celebration

The Ceramic and Glass Industry Foundation (CGIF) returned to the COSI Big Science Celebration on May 2, 2026, in Columbus, Ohio. This year, more than 100 organizations from across science, education, and industry filled the museum's outdoor plaza with hands-on activities. Among them, the CGIF's booth, "The Sweet Science Behind Glass Fibers," drew families eager for hands-on experience with the science behind everyday materials.

The candy fiber pull demonstration was once again at the heart of the booth. Using melted candy, volunteers showed visitors how glass fibers are formed by drawing it into long, thin strands, the same fundamental process behind fiber optic cables and fiberglass insulation.

Kids and families tried pulling the melted candy themselves, and the hands-on nature of the activity made it easy for volunteers to walk guests through the real science in an accessible, engaging way. An additional fiber-optic display helped connect the candy pull demonstration to real-world technology, giving families a clear and memorable picture of where glass fibers show up in everyday life.

The booth also featured ceramic and glass samples that visitors could handle. The space shuttle tile made for a good conversation starter, with visitors saying how impressed they were by its lightweight nature. This comment led into discussions about heat-resistant ceramics and the role materials science plays in aerospace engineering.

The CGIF extends a heartfelt thank you to Allied Mineral Products and the volunteers from ACerS President's Council of Student Advisors who gave their time to make this event a success, and to COSI for hosting



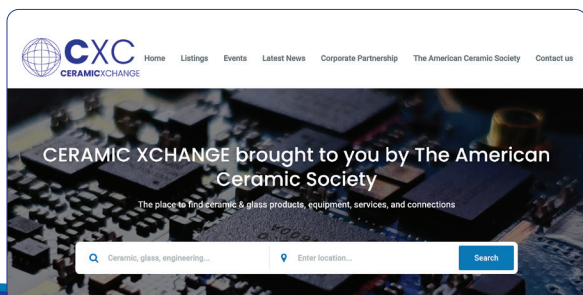
PCSA volunteers and CGIF staff at the CGIF booth for the 2026 COSI Big Science Celebration. From left to right: Melissa Ludington, Randi Swanson, Claire Fleeman, Taylor Murphy, Brittney Hauke, Marcus Fish, Nathan McIlwaine, and Sevag Momjian.

such a well-attended celebration each year. Events such as the Big Science Celebration are a meaningful opportunity to connect with the public and share the reach and relevance of the ceramic and glass industry with the next generation.

Help us continue to empower the next generation of ceramic and glass professionals by giving now at <https://ceramics.org/donate>. ■



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Graphite purification: Challenges, technologies, and future directions

By Hamed Samadi,
Thomas Metzger,
and Manuel Hitz

Graphite has emerged as a cornerstone material for the clean energy transition, playing a critical role in lithium-ion batteries, advanced ceramics, and a wide array of high-technology applications.

Graphite's unique combination of high electrical conductivity, exceptional thermal stability, lubricity, and chemical inertness distinguishes it from other industrial minerals and underpins its indispensability in modern energy and electronics sectors. In lithium-ion batteries, graphite serves as the dominant anode material, enabling efficient lithium-ion intercalation and deintercalation, which is essential for high energy density and long cycle life. Beyond batteries, graphite's high-temperature resilience and corrosion resistance make it vital for refractory linings, crucibles, and components in the semiconductor and nuclear industries.

However, the performance of graphite in these demanding applications is susceptible to impurities such as iron, silicon, sulfur, and various other metallic elements.¹ Even trace amounts of these contaminants can degrade electrochemical performance, reduce thermal conductivity, catalyze unwanted side reactions, or compromise mechanical integrity. These effects are especially problematic in battery, semiconductor, and nuclear applications, where purity requirements often exceed 99.999% carbon content.

The global surge in electric vehicle adoption and the rapid expansion of stationary energy storage systems have driven demand for high-purity graphite to unprecedented levels (Figure 1). According to recent projections, battery and clean energy applications are expected to account for the majority of graphite consumption in the coming decade, with demand for battery-grade graphite projected to quadruple by 2030.²

This explosive growth has exposed significant vulnerabilities in the graphite supply chain, which is currently dominated by

a handful of countries, most notably China. Supply concentration, geopolitical risks, and environmental concerns related to traditional purification methods have underscored the urgent need for advanced, scalable, and sustainable graphite purification technologies to secure future supply and meet the stringent requirements of next-generation energy and electronic systems.

Graphite sources

Graphite exists in both natural and synthetic forms, each with distinct properties, production methods, and industrial uses.

Natural graphite

Natural graphite is classified into three main types based on its crystallinity and morphology: amorphous (microcrystalline), flake, and vein (lump) graphite. None of these types are particularly pure in their natural state, and all require beneficiation and purification before use in high-technology applications.

- **Amorphous graphite** forms through the metamorphism of coal or carbon-rich sedimentary rocks and typically appears as fine-grained, low-crystallinity aggregates. Its relatively low carbon content (typically 70–85 wt.%) and poor crystallinity make it unsuitable for battery-grade applications without extensive processing, and it is more commonly used in lower-value applications such as lubricants and foundry facings.
- **Flake graphite** develops in high-grade metamorphic rocks such as schist, gneiss, and quartzite. It is especially valued for its large flake size, high crystallinity, and ease of exfoliation—properties critical for lithium-ion battery anodes and advanced composite applications. The beneficiation and purification of flake graphite can yield carbon contents exceeding 99.95%. This purity, combined with flake graphite's favorable particle morphology, makes it the preferred feedstock for the battery industry.³
- **Vein graphite**, found in hydrothermal veins, is the rarest and purest form, with high carbon content and unique electrical properties. However, it is geographically limited, notably to Sri Lanka.^{3,4}

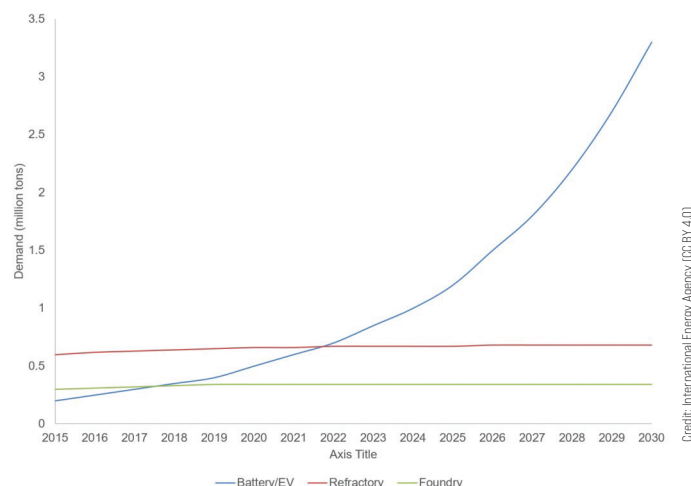


Figure 1. Graphite demand by application over time.²

Synthetic graphite

Synthetic graphite is produced by high-temperature graphitization (typically above 3,000°C) of carbon-rich precursors, such as petroleum coke or coal tar pitch. Through this process, a highly ordered, uniform graphite material is obtained, offering the purity and consistency required for demanding applications such as electric arc furnace electrodes and specialty battery systems. However, synthetic graphite production is significantly more energy intensive and costly than mining and processing natural graphite.⁵

Global supply chains and geopolitical risk

The global graphite supply chain is highly concentrated. China dominates both natural and synthetic graphite production, accounting for more than 80% of global graphite output and an overwhelming 93% of battery anode material production (Figure 2).⁶ This dominance is rooted in China's abundant high-quality deposits, established beneficiation and purification infrastructure, and significant cost advantages.

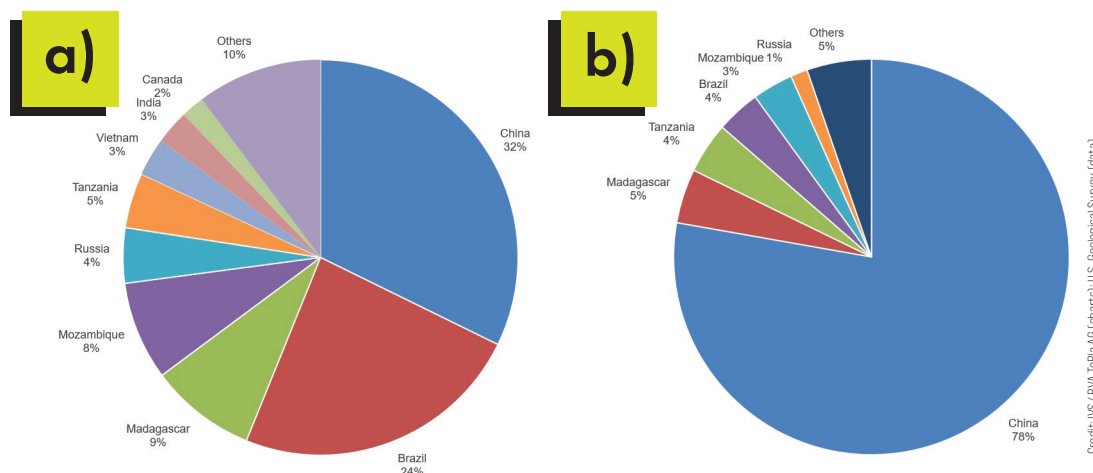


Figure 2. (a) Global natural graphite reserves and (b) production by country (2026). "Reserves" refers to economically extractable quantities identified with reasonable geological certainty; "production" refers to total mined output in the reference year. Chart data comes from Reference 6.

Graphite purification: Challenges, technologies, and future directions

However, such concentration introduces serious supply chain vulnerabilities. China's imposition of graphite export controls in late 2023, which required export licenses for high-purity and shaped graphite products, sent shockwaves through global battery supply chains and highlighted the risks of overreliance on a single dominant supplier.³ Rising geopolitical tensions have since prompted major economies to accelerate efforts to secure alternative sources.

Significant natural graphite reserves are also found in Brazil, Mozambique, Madagascar, and Canada. These countries are actively developing new mining and processing projects to diversify the global supply base. Policy frameworks such as the European Union's Critical Raw Materials Act and incentives under the U.S. Inflation Reduction Act further catalyze investment in domestic and allied graphite projects. The success of these efforts will be critical to ensuring the resilience and sustainability of the graphite supply chain as demand continues accelerating in the clean energy era.³

Purification technologies

A full graphite purification workflow typically encompasses several stages: mining and primary crushing, beneficiation (flotation and classification to remove bulk gangue minerals), chemical or thermal purification to remove residual impurities, and final product finishing (milling, coating, and quality control). The selection and sequencing of purification steps depend on the impurity profile of the specific graphite feed-stock and the purity requirements of the target application.

Wet chemical purification

Chemical purification of graphite is a widely used approach for powdered materials to achieve the high-purity levels required for advanced applications such as lithium-ion batteries and electronic devices. The process typically involves the use of strong acids or alkalis to leach impurity-bearing minerals that are physically or chemically bound to the graphite matrix (e.g., silicates, sulfides, various metal oxides).⁴

The most commonly used chemical reagents are hydrofluoric acid, hydrochloric acid, sulfuric acid, and nitric acid, as well as sodium hydroxide for alkaline leaching.⁷ Each reagent targets specific impurity types.

- **Hydrofluoric acid** is highly effective at dissolving silicate minerals such as quartz and feldspar, which are otherwise highly resistant to acid attack. It enables the removal of silica and aluminosilicate phases that are common in natural graphite concentrates and can be especially detrimental to battery performance.
- **Hydrochloric and sulfuric acids** are effective for dissolving many metallic impurities, such as iron, calcium, and magnesium compounds.

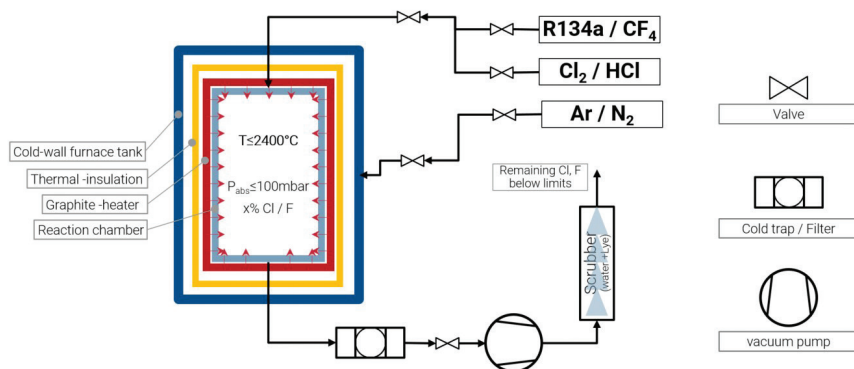


Figure 3. Schematic of a generalized graphite thermal purification reactor.

- **Nitric acid** can oxidize and remove specific organic and metallic contaminants.

In some cases, the high-temperature leaching process of alkaline fusion is employed, which uses sodium hydroxide or potassium hydroxide to convert silicates and sulfides into more soluble forms that can then be leached out in subsequent acid treatments. This multistep approach is often necessary to achieve ultrahigh purity (>99.9 wt.% carbon) demanded by the battery and semiconductor industries.

While chemical purification methods are effective, easily scalable, and can be tailored to address a wide range of impurity profiles, they also present significant environmental and operational challenges. The use of large volumes of strong acids and bases generates substantial quantities of hazardous liquid and solid waste, requiring robust treatment and disposal systems to prevent environmental contamination. In particular, hydrofluoric acid is highly toxic and corrosive, posing serious risks to workers and requiring specialized equipment and handling protocols. The management of spent reagents and the neutralization of acidic effluents are critical considerations for the sustainable operation of chemical purification plants.⁸

As environmental regulations tighten and sustainability becomes a greater concern, there is increasing interest in developing alternative purification methods or closed-loop chemical processes that minimize reagent consumption and waste generation.

Thermal purification

Thermal purification is a cornerstone technology for producing ultrahigh-purity graphite, especially for applications where even trace levels of metallic or nonmetallic impurities are unacceptable. In this process (Figure 3), graphite is subjected to extremely high temperatures (typically between 2,400°C and 3,000°C depending on the impurity profile and target purity) under vacuum or an inert (argon or nitrogen) atmosphere to prevent oxidation and preserve the graphite structure.⁸

At these elevated temperatures, several purification mechanisms come into play⁹:

- **Volatilization of impurities:** Many metallic and non-metallic impurities (such as sulfur, lead, and alkali metals) have relatively low vapor pressures at high temperatures

and can be directly vaporized and removed from the graphite matrix. Vacuum conditions enhance this effect by lowering the partial pressure of volatile species, facilitating their escape from the graphite surface.

- **Halogen-assisted purification:** For more refractory impurities that form stable carbides and oxides—and are therefore resistant to simple volatilization—halogen gases are introduced into the hot zone. Chlorine gas is particularly effective for removing metallic impurities such as iron, calcium, and aluminum, reacting with them to form volatile metal chlorides (e.g., FeCl_3 , AlCl_3) that are swept out of the reaction zone. Fluorine-based compounds are preferentially used for silicon and silicate-type impurities, forming highly volatile silicon tetrafluoride that is readily removed. These volatile halide compounds are captured in downstream cold traps or neutralized in wet scrubbers, ensuring environmental compliance.

Thermal purification is highly effective at achieving carbon purities exceeding 99.999 wt.%, making it the method of choice for battery anodes, nuclear graphite, and semiconductor applications. The process is also scalable for industrial use, with large batch furnaces capable of treating hundreds of kilograms to several tons per cycle.

However, the method is energy intensive due to the extreme temperatures required, and furnace design must account for thermal stresses, efficient heat transfer, and robust insulation. The use of halogen gases also necessitates stringent safety and environmental controls, although it should be noted that the quantities of hazardous byproducts generated are substantially smaller than those produced by wet chemical purification routes.

Recent advances in reactor design have focused on improving throughput, energy efficiency, and process control. Notably, the development of fluidized bed reactors has enabled more uniform heating and rapid impurity removal. In a fluidized bed reactor, graphite particles are suspended in a stream of inert or reactive gas, enabling excellent heat and mass transfer while allowing continuous feeding and product removal. These innovations are helping to reduce the operational costs and environmental footprint of thermal purification, making it more attractive for large-scale, high-purity graphite production.⁸

Purification solutions at IVS

Building on the established principles of thermal and halogen-assisted purification described above, PVA Industrial Vacuum Systems GmbH (IVS)—a subsidiary of PVA TePla AG (Wettenberg, Germany)—has developed industrial-scale furnace systems that integrate both approaches into a highly engineered, automated platform. IVS offers advanced graphite purification solutions based on high-temperature vacuum and partial-pressure furnaces (Figure 4), engineered for a wide range of applications including graphite solids, graphite powders, and carbon fiber composite treatments.



Figure 4. Example of an IVS bottom loader graphite purification solution. The flexibility of the furnace platform allows IVS to support both established and next-generation markets, and the modular design enables systems to be scaled and configured to match specific production volumes and feedstock characteristics.

The purification process is designed to address both volatile and nonvolatile impurities in a controlled, sequential manner. Sulfur and other volatile species are removed under high vacuum at elevated temperatures. For more refractory metallic impurities that form stable carbides, which cannot be removed via thermal processes alone, IVS systems introduce chlorine and fluorine gases at precisely controlled flow rates and temperatures to form volatile halide compounds, which are then purged from the hot zone. Chlorine is used preferentially for metallic contaminants such as iron and calcium, while fluorine is employed for silicon and silicate-type impurities, reflecting the distinct chemistry of each reagent class. The exhaust gas is routed through cold traps and filters, and any remaining halogens are neutralized in a wet scrubber to ensure environmental compliance.

Safety and environmental controls are integral to the IVS design philosophy. Wet scrubbers for exhaust gas treatment, robust pressure vessel engineering, and controlled process cooling water supply ensure safe operation even at high temperatures and with reactive gases. The systems are adaptable to site-specific requirements and can be equipped with a range of safety and process integration accessories.

IVS furnaces feature fully automated process sequences, including vessel evacuation, vacuum or partial-pressure heating, controlled gas flow, and programmable cooling cycles. The systems support both manual and automatic loading tools, as well as safe gas bottle storage and changeover, thus reducing operator intervention and improving process reproducibility.

All together, these design features enable consistent delivery of carbon purities exceeding 99.999 wt.% at industrial throughput, supporting customer qualification requirements for battery anode material, silicon carbide crystal growth, advanced ceramics, and emerging applications such as carbon nanotubes and graphene.

Graphite purification: Challenges, technologies, and future directions

The future of graphite purification

Graphite purification stands as a technically demanding, multistage process that is fundamental to the performance and reliability of advanced batteries, ceramics, and electronic devices. The stringent purity requirements—often exceeding 99.999 wt.% carbon content—are driven by the sensitivity of these applications to trace impurities, which can degrade electrochemical behavior, thermal conductivity, and mechanical stability. Achieving such high purity involves a sequence of beneficiation, chemical leaching, thermal treatment, and product finishing steps, each tailored to the specific impurity profile and end-use requirements of the graphite feedstock.

Recent advances in chemical and thermal purification technologies have significantly improved the efficiency and effectiveness of impurity removal. Chemical purification remains highly effective for dissolving a wide range of contaminants, including metallic species and silicates. Thermal and halogen-assisted processes are better suited for volatilizing more refractory metals and silicate phases, and ongoing reactor design improvements (including fluidized bed configurations) are enhancing throughput and energy efficiency.

Despite this progress, the graphite industry continues to face substantial challenges. Environmental concerns stemming from the use of hazardous reagents, energy-intensive operations, and waste generation are increasingly coming under regulatory scrutiny worldwide. The global supply chain remains highly concentrated, exposing downstream industries to geopolitical and logistical risks that have already materialized in the form of export controls and trade restrictions.

Looking ahead, several emerging developments are poised to shape the future of graphite purification.

- **Electrochemical purification** is an area of active research, offering the potential to selectively dissolve metallic impurities at lower temperatures and without the use of bulk acid volumes, potentially offering a more energy-efficient and environmentally benign alternative for certain impurity profiles.
- **Battery graphite recycling** is moving from pilot to commercial scale, with recovered anode graphite requiring reconditioning and purification before reuse. Developing efficient and cost-effective purification routes for recycled graphite will be essential to closing the loop on battery material supply chains.
- **AI-driven process control and digital twins** are increasingly being applied to complex high-temperature processes, enabling real-time optimization of temperature profiles, gas flow rates, and cycle times to maximize purity and throughput while minimizing energy consumption and reagent use.
- **Regulatory and policy frameworks**, including the EU Critical Raw Materials Act and incentives under the U.S. Inflation Reduction Act, will continue to shape investment in domestic purification capacity, encouraging the buildout of supply chains outside of China and raising the bar for environmental compliance.

The future of graphite purification will depend on integrating advanced process control, robust environmental

PVA TePla: Founding and future goals

Established in 1991, Wetztenberg, Germany-based PVA TePla AG is a global provider of advanced materials processing and metrology technologies. Its portfolio includes high-temperature vacuum and partial-pressure furnaces for applications such as graphite purification, diffusion bonding, brazing, and sintering, as well as crystal growing systems, plasma treatment technologies, and precision metrology solutions.

PVA TePla AG continues to broaden its technological capabilities through strategic acquisitions and ongoing development within its Technology Hub, which focuses on next-generation materials processing and advanced inspection technologies. ■

safeguards, and industrial scalability. Companies such as IVS are at the forefront of this evolution, offering state-of-the-art furnace systems that combine automated process management, closed-loop gas handling, and modular design to deliver consistent, ultrahigh-purity graphite at an industrial scale. Such innovations not only address the technical and regulatory challenges of modern graphite production but also support the resilience and sustainability of the global supply chain.

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US continues strengthening domestic supply chains to reduce reliance on foreign sources

By Helen Widman

In recent years, the United States has made significant strides in transforming its mineral supply chains and reliance on foreign mineral sources, as reported in the annual United States Geological Survey *Mineral Commodity Summaries*.¹

The USGS *Mineral Commodity Summaries* report spotlights events, trends, and issues from the past year in the nonfuel mineral industry. Each August, the *ACerS Bulletin* shares some of the key facts covered in the report.

In 2025, U.S. nonfuel mineral production reached an estimated \$112 billion, a 5.6% increase from 2024. The total value of industrial minerals production was \$73.7 billion, which is 2% more than the revised total of 2024. Of this total, an estimated \$39.4 billion came from construction aggregates production, including construction sand, gravel, and crushed stone. Crushed stone once again led the U.S. nonfuel mineral commodities list with a production value of \$26.8 billion (24% of total value).

The metals sector was a mixed bag of price fluctuations. The production values of cobalt and nickel increased by 80% and 19%, respectively, compared to 2024. In contrast, the production value of lithium decreased by 16%. Meanwhile, the production value of natural aggregates increased by 4%, even though 2025 production volumes decreased by 1% compared to 2024.

The USGS List of Critical Minerals notably expanded from 50 to 60 minerals to help encourage domestic production. The additions are boron, copper, lead, metallurgical coal, phosphate rock, potash, rhenium, silicon, silver, and uranium.

As part of the U.S. government's ongoing strategy to reduce reliance on foreign supply chains, various investments and congressional acts were implemented aimed at strengthening domestic critical minerals production. For example, the Department of Defense invested \$1 billion in the critical minerals sector throughout 2025, including a collaboration with a Korean company on a \$7.4 billion smelter project in Clarksville, Tenn.

In April 2025, Executive Order 14272 instructed the Department of Commerce to investigate certain critical minerals for national security purposes, as well as products manufactured from minerals such as batteries, microprocessors, and renewable energy system components.² A few months later, in July 2025, the One Big Beautiful Bill Act was passed, which provides \$2 billion for stockpiling of critical minerals and \$5 billion

for the Secretary of Defense to invest in production of niobium, scandium, titanium, and other critical minerals.³

Regarding critical minerals facilities, several projects broke ground, including multiple new facilities producing copper in states such as Arizona, Kentucky, and Georgia. Demand for copper has spiked in recent years as the demand for data centers and electric vehicles has increased.

Despite efforts to strengthen domestic supply chains, the U.S. still relies on foreign sources for certain raw or processed materials. In 2025, the U.S. was 100% net import reliant on 13 of the 60 critical mineral commodities and at least 50% or more net import reliant on 20 others. Recycling served as the only domestic source for antimony, bismuth, chromium, magnesium metal, tin, tungsten, and vanadium.

Besides the ongoing trade policy disputes between the U.S. and China in 2025, both countries sought to expand their base of support globally. China formed an International Economic and Trade Cooperation Initiative on Green Mining and Minerals in late 2025,⁴ while the U.S. launched the Forum on Resource Geostrategic Engagement in early 2026.⁵

The next two pages contain a table summarizing some of the statistics and trends for a variety of mineral commodities that serve the ceramic and glass industries. Access the complete USGS report at <https://pubs.usgs.gov/publication/mcs2026>.

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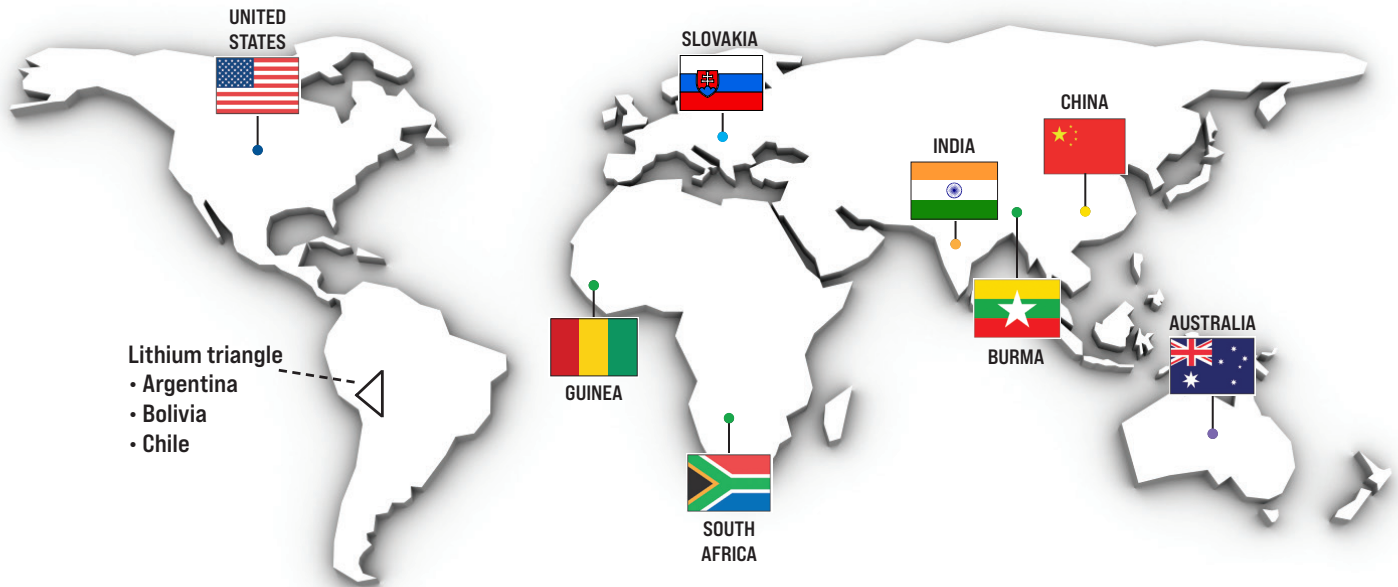
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2026 USGS MINERAL COMMODITY SUMMARIES

Leading producer highlights



	End-use industries	Trend in global production	US production	US import/export	World reserves	Leading producer
ABRASIVES (fused aluminum oxide and silicon carbide)	Bonded and coated abrasive products	0.8% decrease for fused aluminum oxide; No change for silicon carbide	20,000 metric tons fused aluminum oxide; 30,000 metric tons silicon carbide	>95% net import reliance for fused aluminum oxide; 74% net import reliance for silicon carbide	Fused aluminum oxide: adequate in the Western Hemisphere; Silicon carbide: adequate domestic supply	Fused aluminum oxide: China Silicon carbide: China 
BAUXITE AND ALUMINA	Bauxite: refined for alumina or aluminum hydroxide, abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills; Alumina: used in production of aluminum, abrasives, ceramics, chemicals, refractories	2.8% increase for bauxite; 5.6% increase for alumina	Bauxite production information withheld; 710,000 metric tons alumina	>75% net import reliance for bauxite; 71% net import reliance for alumina	Between 55 billion and 75 billion metric tons bauxite	Bauxite: Guinea  Alumina: China 
CEMENT	Construction	2.6% decrease for cement; no change for clinker capacity	84,000 metric tons cement; 69,000 metric tons clinker	21% net import reliance (4.5% decrease)	Reserves of lime and stone (crushed) are very large and plentiful, respectively	China 
CLAYS	Tile, absorbents, fillers, extenders, binders, drilling mud, construction, paper coating, brick	3.1% increase for bentonite; 0.7% decrease for Fuller's earth; 1.8% increase for kaolin	26,000 metric tons (50.0% common clay, 18.5% kaolin, 15.8% bentonite, 9.2% Fuller's earth, 6.5% other)	Net exporter	Extremely large	Bentonite: United States  Fuller's earth: United States  Kaolin: India 
FELDSPAR	Glass, ceramic tile, pottery	0.3% decrease	440,000 metric tons (marketable production)	18% net import reliance	More than adequate	India 
GALLIUM	Integrated circuits and optoelectronic devices, including laser diodes, light-emitting diodes, photodetectors, and solar cells	6.1% increase	None (primary)	100% net import reliance	Gallium contained in world resources of bauxite is estimated to exceed 1 million tons, and significant quantities could be contained in zinc.	China 

	End-use industries	Trend in global production	US production	US import/export	World reserves	Leading producer
GRAPHITE (natural)	Batteries, brake linings, lubricants, powdered metals, refractory applications, steelmaking	16.1% increase	None	100% net import reliance	>800 million metric tons	China 
INDIUM	Flat-panel displays, alloys and solders, compounds, electrical components and semiconductors, research	0.9% increase	None	100% net import reliance	Estimate unavailable	China 
IRON and STEEL	Construction, automotive, machinery and equipment, oil and gas, appliances	1.6% increase for pig iron; 1.1% increase for raw steel	21 million metric tons for pig iron; 82 million metric tons for raw steel	13% net import reliance	N/A	Iron and steel: China 
KYANITE	Refractories, abrasives, ceramic products, foundry products, precision casting molds	Cannot be calculated	80,000 metric tons	Net exporter	Large	Kyanite: United States  Andalusite: South Africa 
LITHIUM	Batteries, ceramics and glass, lubricating greases, air treatment, mold flux powders, medical uses	30.6% increase	Withheld	>50% net import reliance	Substantial increase worldwide to total ~150 million tons	Australia 
MICA (scrap and flake)	Joint compound, oil-well-drilling additives, paint, roofing, and rubber products	6.9% decrease	26,000 metric tons sold or used; 59,000 metric tons ground	100% net import reliance	More than adequate	China 
RARE EARTHS	Catalysts, ceramics, glass, metallurgical applications, alloys, polishing	2.6% increase	51,000 metric tons mineral concentrations	67% net importer for compounds and metals; net exporter for mineral concentrates	Relatively abundant in Earth's crust, but minable concentrations less common	China 
SODA ASH	Glass, chemicals, distributors, flue gas desulfurization, soap and detergents, pulp and paper, water treatments	0.6% increase	12,000 metric tons	Net exporter	About 47 billion metric tons of identified natural soda ash resources; synthetic soda ash practically inexhaustible but costlier to produce	United States 
TITANIUM DIOXIDE (pigment)	Paints, plastics, paper, catalysts, ceramics, coated fabrics and textiles, floor coverings, printing ink, roofing granules	N/A	1 million metric tons (pigment)	Net exporter	Data not available for pigment	China 
YTTRIUM	Catalysts, ceramics, electronics, lasers, metallurgy, phosphors	Estimated to be between 10,000 and 15,000 metric tons	N/A	100% net import reliance	Large resources of yttrium in monazite and xenotime are available worldwide	Burma  and China 
ZEOLITES (natural)	Animal feed, odor control, unspecified end uses, water purification, wastewater treatment, gas absorbent, fertilizer carrier, pet litter, oil and grease absorbent, fungicide or pesticide carrier, desiccant, aquaculture, catalyst	4.8% increase	80,000 metric tons	Net exporter	Estimate not available but likely sufficient	Slovakia 

Novel superhard diamond composites synthesized through established technologies

By Mathias Herrmann, Björn Matthey, Steffen Kunze, Jerry LaSalvia, and Anthony DiGiovanni

Although many people associate diamonds with expensive gemstones, the vast majority of diamonds serve as industrial materials instead.

Diamond is the hardest natural material available in abundance. It also has the highest thermal conductivity of any known bulk material, and it provides broad transparency from deep ultraviolet to infrared. These properties have led humans to use diamonds as tools for more than four millennia,¹ particularly in applications involving abrasive machining.

Most modern industrial diamonds are grown in the lab, as synthetic manufacturing offers reliable performance and consistent supply to meet the enormous market demand. Market reports cite volumes of about 15 billion carats for manufactured industrial diamond powder in 2025 and 2026, and projected compound annual growth rates ranging from 6.4–8.2% to 2033.^{2,3} Learn more about the global industrial diamond market in the sidebar “Global markets for industrial diamonds.”

To create synthetic diamonds, high-pressure, high-temperature (HPHT) processes are typically used, although chemical vapor deposition (CVD) processes are increasingly used as well. While diamond materials synthesized through these methods offer exceptional material properties—and their costs have reduced

considerably since their introduction—they remain prohibitively expensive or unable to meet challenging demands for larger and complex parts in thermal management and wear applications.

In recent years, our team and other groups have developed a new class of synthetic diamond materials called silicon carbide-bonded diamond composites that can be produced using cost-effective, established ceramic manufacturing techniques with virtually no geometric restrictions.^{4–7} This development was accelerated by the falling prices of diamond grit and the increasing demand for components with both high wear resistance and high thermal conductivity for a variety of applications. The fundamentals of this innovative diamond–SiC production method and the unique properties of these materials are described in the following sections.

Current synthetic diamond production practices

Besides grinding wheels and loose diamond abrasive grains, which will not be discussed here, bulk polycrystalline diamond (PCD) materials and CVD diamond coatings are the main types of industrial diamond materials.

PCD materials are commonly used for compact cutting inserts, which were originally developed by General Electric in the early 1970s to support drilling technologies in the oil and gas industry.⁸ These materials are now also used for rock

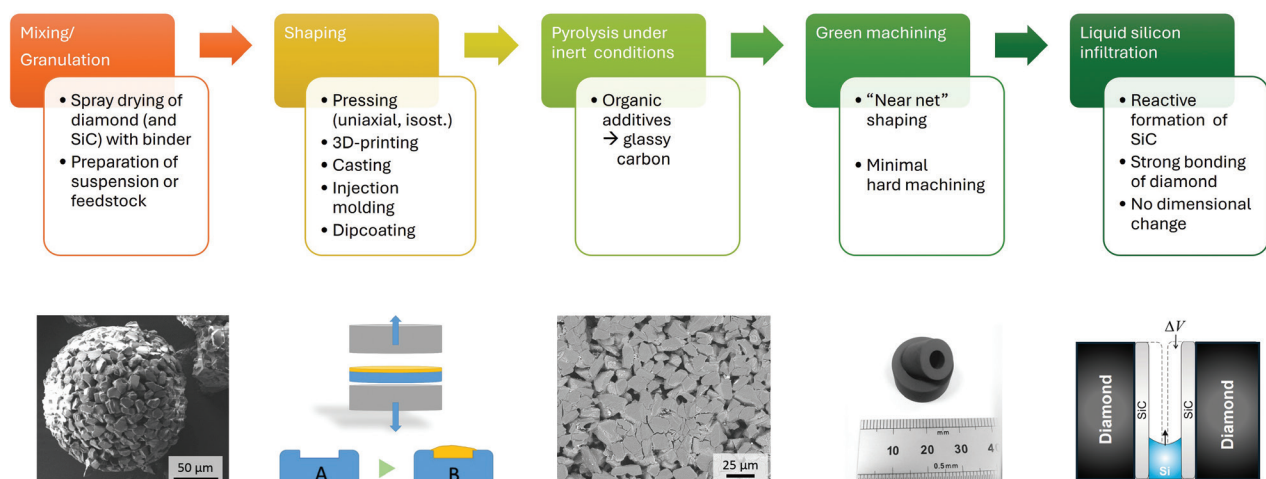


Figure 1. Schematic of the production process for the novel diamond–SiC composites.

drilling and machining of stone, wood, fiber composites, and nonferrous metals alike.

PCD materials are produced through HPHT processes (4–6 GPa, 1,300–1,600°C), which limits the materials' possible lateral dimensions. They often are sintered directly onto tungsten carbide substrates, which contain cobalt binders that catalytically sinter diamond grains in a more industrially tractable pressure and temperature regime of the carbon phase diagram.

Modifying the composition and diamond grain size of PCD materials can result in a wide variation in properties. In particular, different toughness levels can be achieved with only a moderate reduction in hardness. For example, cobalt binders increase toughness, but they lead to degradation of the cutting edge during high-temperature applications due to reverse catalytic reactions with the diamond phase. On the other hand, chemical leaching of the catalytic cobalt can enhance thermal stability during the cutting processes.^{9,10} Achieving binder-free bulk PCD materials is possible, but it requires high pressures and temperatures (16 GPa and 2,300°C in one study¹¹).

CVD diamond coatings have been developed in recent years for wear-resistant applications, such as coated cutting tools and mechanical seals.¹² Thicker detached coatings are used as windows for sensors and lasers, beam splitters for space applications, and other thermal management devices. Also, broken CVD layers are increasingly being used to produce synthetic gem-quality and industrial diamonds.

Both planar components and curved surfaces, such as high-precision spheres, can be produced using this method.¹³ However, deposition rates range from less than 1 µm/h to about 100 µm/h depending on the specific CVD method used. That means CVD technology can only be used to effectively produce components with limited thickness. Once the thickness reaches about 2 mm, residual stresses can cause microcracks, which can lead to a deterioration in the material's properties.

Manufacturing of diamond–SiC composites

The pressureless reactive infiltration process used to create the novel diamond–SiC composites is analogous to the established manufacturing method for producing reaction-bonded SiC materials (RB-SiC) (Figure 1). First, porous diamond preforms are produced from diamond powder and an organic binder. Virtually all ceramic forming methods can be used to produce these preforms, including pressing, casting, extrusion, injection molding, and even additive manufacturing methods (such as fused filament forming and lithography). To achieve a high diamond and low free silicon content, it is necessary to achieve a high packing density of the diamonds in the preform. Therefore, powder-bed-based methods such as ink jetting are less suitable for such materials.

After pyrolysis under inert conditions, the diamond preform is infiltrated with liquid silicon in a vacuum at temperatures between 1,450–1,600°C. During liquid silicon infiltration, commonly known as LSI, silicon reacts with the carbon from the organic binder and, to some extent, with the diamond grains. During siliconization, cubic β-SiC is formed on the diamond surface. This formation is accompanied by a 266 vol.%

increase of the solid phases, while the component dimensions remain constant. For this reason, there are limitations regarding the minimum pore channel diameter in the diamond preform, just like the restrictions in the production of RB-SiC.

Infiltration works effectively with diamond particle sizes greater than 10 µm, as the pore size in the preform is determined by the diamond particle size. If the diamond particle sizes are too large, a high proportion of unreacted silicon remains in the pores of the material because the SiC forming on the diamond surface passivates the diamond (Figure 2). To achieve high diamond content and a low content of free silicon, optimized polymodal diamond mixtures are necessary. With optimized mixtures and process parameters, much lower silicon contents (1–5 vol.%) are possible than in conventional RB-SiC materials (typically greater than 10 vol.%).

Global markets for industrial diamonds

Industrial diamond usage is concentrated in a few key application areas.^a In the traditional grinding, machining, and polishing sector, diamond powder is used in diamond suspensions, grinding wheels (with metal, ceramic, and plastic bonds), wire saws, and as a raw material for polycrystalline diamond materials. Diamond-based thermal management solutions, which exploit the high thermal conductivity of diamond, are developing particularly rapidly due to the emergence and growth of modern electronic chip designs and power electronics.

Industrial diamond powder prices range from \$250 to \$2,000 per kilogram, depending on quality and particle size. Due to their low density, the price per unit volume is up to seven times lower than tungsten carbide powder, which is the raw material for many wear-resistant materials.

Synthetic industrial diamonds can be produced from a wide variety of carbon sources available worldwide. Yet China dominates industrial diamond production (~70–90 vol.%),^b followed by the United States and Russia as distant second and third sources. Together, these three countries account for about 99 vol.% of global production.^c

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^a"Industrial diamond market report 2030," Strategic Market Research. Published February 2026. <https://tinyurl.com/5x6rbtuu>

^bW. Powell, "Dazzle, dazzle. The rise of China's lab-grown diamond sector," Warwick Powell's Substack. Published 19 Feb. 2026. <https://tinyurl.com/2p9hvx72>

^c*Mineral Commodity Summaries 2026*, U.S. Geological Survey, Reston, Va., 2026.

*All references verified as of June 12, 2026. ■

Novel superhard diamond composites synthesized through established technologies

The maximum infiltration temperature is determined by the onset of graphitization of the diamond grains, especially at the grain boundaries. Above an infiltration temperature of about 1,600–1,650°C, thin graphite layers will form at the SiC–diamond interface. Fortunately, these thin graphite layers (less than 50–100 nm) do not appear to cause any significant reduction in strength, wear resistance, or thermal properties.^{14–16} This fact makes the manufacturing process tolerant to minor variations in the temperature distribution within the furnace during siliconization.

Infiltration of the diamond preforms occurs without significant changes in the component's dimensions. Therefore, the material can be manufactured close to the final contour with tight tolerances (on the same order of magnitude as the grain size of the diamonds used, 50–200 µm). As long as these tolerances are sufficient for the application, the component is cost effective. The manufacturing costs are also roughly equivalent to those of RB-SiC components.

Notably, because the infiltration of the diamond preform takes place under the same conditions as in the production of RB-SiC materials, there is the potential to combine diamond-SiC and RB-SiC materials in graded components. Such a capability would make it possible to manufacture components in which the SiC-bonded diamond is present only in the areas where it is needed for the application, thus simplifying the finishing process and reducing manufacturing costs. We recently demonstrated this potential by introducing SiC-bonded diamond regions into sintered SiC materials.¹⁷

If surface finishing is required, the material's high wear resistance hinders mechanical machining. This obstacle can be circumvented using laser machining and electrical discharge machining (no surface stresses are induced with modern ultrashort pulse lasers). Surface polishing is also possible using methods established for diamond layers.

The resulting microstructure consists of diamond grains embedded in a 3D framework of cubic β -SiC. The majority of the SiC grains grow heteroepitaxially onto the diamond grains,

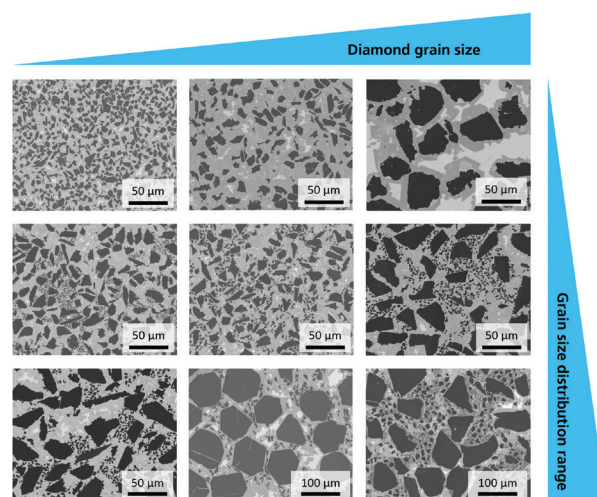


Figure 2. Microstructure variations in the diamond-SiC composites. Black: diamond; gray: silicon carbide; white: unreacted silicon.

resulting in strong integration of the diamond grains into the SiC matrix. Micromechanical measurements have shown that the strength of the SiC–diamond interface corresponds to the strength of the diamond–diamond interface in PCD materials.

In addition to the micrometer-sized crystals formed epitaxially on the diamond grains, there are also regions of nanocrystalline SiC, some of which still contain nanocrystalline residual silicon. The extent of these regions can be influenced in part by mixing SiC powders into the original diamond preform. This addition leads to a change in microstructure formation due to the epitaxial growth of secondary SiC on the added SiC particles, which competes with the formation of SiC layers on the diamond surfaces.¹⁸ Furthermore, the diamond content in the material can be adjusted over a wide range by mixing diamond and SiC powders in the preform. Low diamond contents (10–20 vol.%) can be used primarily to reduce the free silicon content in RB-SiC materials. More details of the structural formation are summarized in References 19, 20, and 21.

Because the diamond-SiC composites can be produced

without pressure, they offer significant cost advantages over PCD materials, which require HPHT processes for their manufacture. Furthermore, due to the wide range of shaping methods available, they allow for much greater geometric diversity and dimensions, which is a decisive advantage over CVD diamond materials. The dimensions are limited only by the size of conventional high-temperature vacuum furnaces.

Table 1. Typical properties of the diamond-SiC composites compared to other superhard materials. Data from References 13, 22–26.

Property	Unit	Diamond-SiC	PCD	CVD	WC/Co	B ₄ C
Density	g/cm ³	3.2–3.4	3.5–4.2	3.5	14–15.2	2.5
Modulus of elasticity	GPa	600–850	700–1,000	1,050	520–650	390–440
Hardness	GPa	>40	50	100	13–17	40
Thermal conductivity	W/(mK)	400–850	400–600	1,200–2,000	65–100	28
Thermal expansion	10 ⁻⁶ /K	1.8–2.2	2.5–4	1	5–6	4.5–6
Strength	MPa	300–550	600–1,900	300–800	1,700–3,000	400
Fracture toughness	MPa • m ^{1/2}	4–5	6–9	6–8	7–13	2–3

Properties of diamond–SiC composites

An overview of the properties achievable with the diamond–SiC composites, as compared to other superhard materials, is provided in Table 1.^{13,22–26} Even though the maximum diamond content achieved to date in the composite (~70–75 vol.%) is slightly below that of PCD materials, it still achieves properties that are excellent for both extreme wear applications and thermal management solutions.

The properties of the diamond–SiC composites depend heavily on the material's diamond content, grain size, and residual silicon content. As the diamond content increases, the Young's modulus, hardness, and thermal conductivity rise, while thermal expansion decreases slightly. At the same diamond content, a lower residual silicon content leads to a higher Young's modulus and higher thermal conductivity.

The Young's modulus is highly dependent on the diamond content, as the Young's modulus of SiC (about 400 GPa) and diamond (1,050–1,150 GPa) differ significantly. This relationship can be estimated using the Hashin–Shtrikman model, as shown in Figure 3.^{27–29} In this model, the matrix is considered to be RB-SiC. This value may vary slightly depending on the residual silicon content.

The diamond–SiC composites with diamond contents greater than 40 vol.% are a superhard material with hardnesses of more than 40–45 GPa. However, measuring the exact hardness of the composites is difficult, as the size of the indentations is often smaller than the diamond grain sizes used, which range from 20 to 100 μm .

The high hardness also results in high wear resistance under both sliding wear and abrasive wear. In both cases, the strong bonding of the diamond to the SiC matrix plays a decisive role. In the initial stage of wear, there is minimal wear of the SiC matrix. As a result, the diamond grains protrude and therefore determine the extent of subsequent wear. One of our studies demonstrated an approximately 10 times better wear resistance under sandblasting conditions for the diamond–SiC composites compared to boron carbide materials.¹⁶

In sliding wear applications, very low coefficients of friction have been demonstrated in addition to low wear, making the material attractive for highly stressed bearings and seals.¹⁷ Due to the low residual silicon content (< 1 vol.%), the cor-

rosion resistance is very high in not only acidic but also alkaline media. This behavior is completely different to standard RB-SiC, which has low corrosion resistance in alkaline media.

In recent years, significant attention has been focused on investigating the relationships between microstructure and thermal properties in various material classes. Figure 4a shows the diamond–SiC composites in comparison to other commonly used materials for thermal management.³⁰ Like other diamond-based materials, the diamond–SiC composites far exceed the thermal conductivity values of metals and other ceramics. The thermal conductivity values of the diamond–SiC composites produced without pressure exceed those of typical PCD materials. However, due to their lower diamond content, they are slightly lower than those of CVD diamond.

Thermal conductivities of up to 700 W/mK have been consistently achieved for typical polymodal diamond grain size distributions up to 200 μm . For grain sizes up to 50 μm and diamond contents around 50 vol.%, values of 400–600 W/mK can be achieved.¹⁴ Using specialized manufacturing technologies

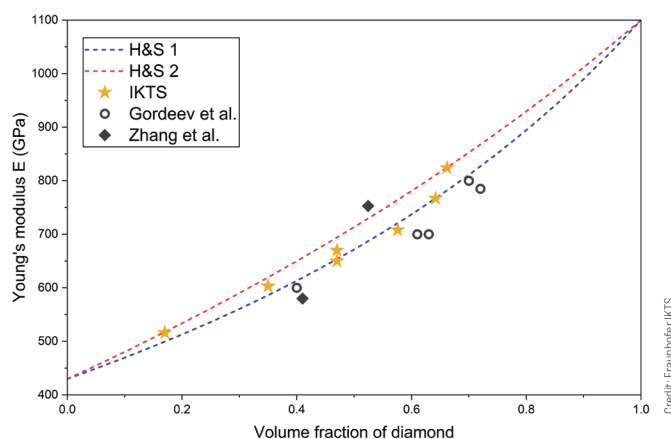


Figure 3. Dependence of the Young's modulus on the volume fraction of diamond in the diamond–SiC composites. The lines represent the lower (H&S-1) and upper (H&S-2) limits of the Hashin–Shtrikman model.²⁷ The matrix was considered to be RB-SiC. The variation in the silicon content within the composites can partially explain the scatter in the experimental data. Additionally, the variation in diamond content is on the order of up to 5 vol.% for materials with high diamond content. IKTS data provided by the authors; data for Gordeev and Zhang from references 28 and 29.

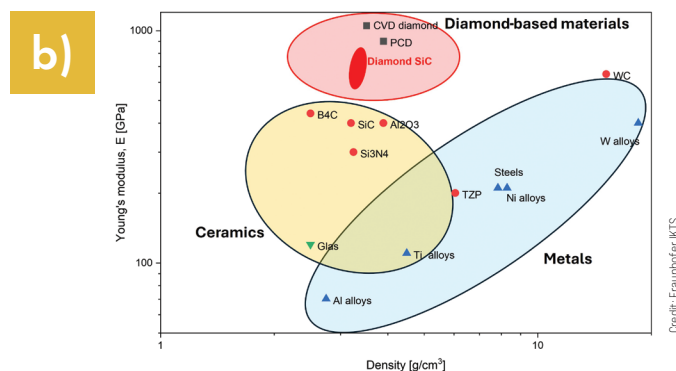
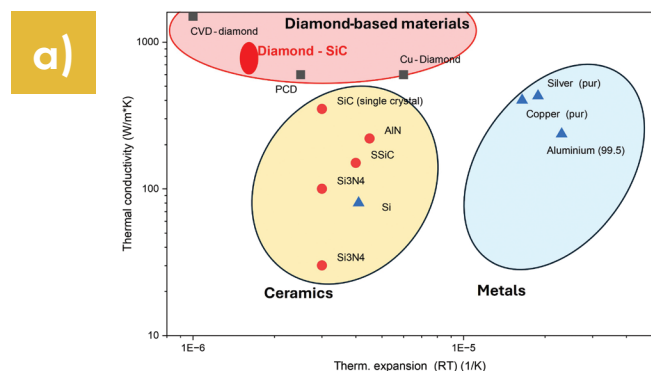


Figure 4. Ashby plot of a) thermal conductivity and b) Young's modulus for the diamond–SiC composites compared with other material classes. Based on figures in Reference 30.

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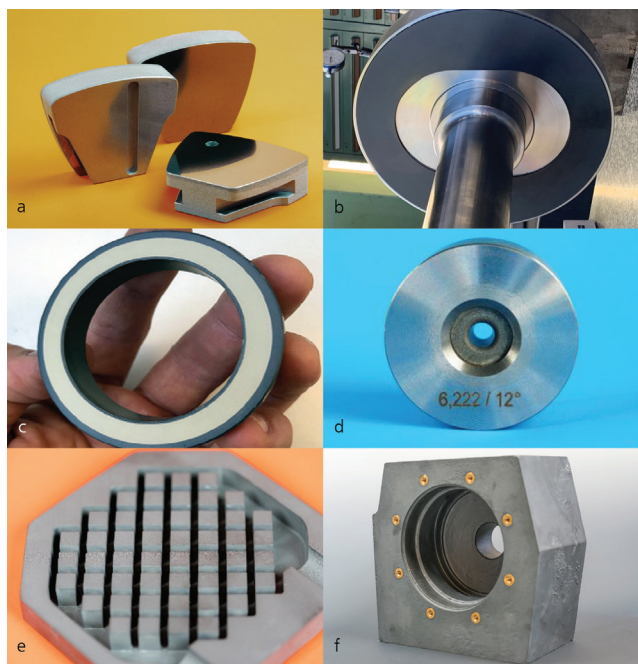


Figure 5. Components made of the diamond–SiC composites: (a) tilting pads and (b) thrust collar of a tilting pad thrust bearing; (c) seal made of silicon-infiltrated SiC with diamond–SiC inlays in green condition¹⁷; (d) drawing die; (e) cooling element; and (f) pump housing with diamond–SiC lining.

and 400 μm diamond grain sizes, one study obtained a value of 840 W/mK for its diamond-based material.³¹ Such values also appear feasible for materials with smaller diamond grain sizes (up to 200 μm) with appropriate optimization of the composition and technology.

Also noteworthy are the high values of volumetric heat capacity and flexural vibration (Young's modulus^{1/2}/density) that, according to Ashby,³⁰ are essential for minimizing thermal distortion. On this basis, in addition to components for thermal management, very stiff, wear-resistant components for precision measuring instruments or mounts for optical systems can be manufactured using the diamond–SiC composites.

A disadvantage of the diamond–SiC composites is the low oxidation resistance of the diamond, which limits the maximum operating temperature under oxidizing conditions to 600–800°C. The reason for this low resistance is that the diamond grains in materials with a high diamond content form a 3D skeleton, which allows the diamond grains to oxidize at greater depths.³²

Some studies have shown that doping with boron can provide diamonds with slightly higher oxidation stability.³³ In addition, the percolation of diamond grains can be prevented in materials with a lower diamond content (30–50 vol.%), thus containing oxidation to the material's surface. Furthermore, depending on the application environment, grading the diamond content and modifying the ceramic matrix offers paths for enhancing oxidation resistance while maintaining other physical and mechanical properties.

Properties of the diamond–SiC composites can also be modified by adjusting the packing density of the diamond grains and adding other components. For example, the addi-

tion of pyrolytic carbon²¹ or fine SiC powder¹⁸ modify the structure of the SiC matrix and the SiC–diamond interface while also reducing the content of free silicon in the matrix. Similarly, the infiltration of titanium silicide melts results in materials with a matrix of in-situ formed SiC and the MAX phase Ti_3SiC_2 , as well as a minimized free silicon content.³⁴ These modifications are expected to improve the toughness and strength of the materials, and similar effects can be achieved by adding transition metal carbide powders (e.g., TiC, ZrC, TaC, HfC).

Doping not only influences the structure and mechanical properties of the diamond–SiC composites but also the electrical properties. Because diamond, SiC, and silicon are all semiconductors, the electrical conductivity can be controlled over a wide range by adjusting the purity or doping of the components. Research on this topic is still in its early stages, as high-purity starting materials have not typically been used to date.

Figure 4 shows the thermal and elastic properties of the diamond–SiC composites in relation to other wear and structural materials and typical materials for thermal management.³⁰ The properties shown indicate that these composites offer significant advantages for both demanding wear applications and thermal management components. Application studies to leverage these advantages are currently underway in various directions. For instance, studies by Chinese researchers primarily look at components with high thermal conductivity for usage in applications such as power electronics and high-powered lasers,^{7,29} while a study by Russian researchers revealed the potential of the diamond–SiC composites for ballistic applications.³⁵

Components made from the diamond–SiC composites have been successfully tested as bearing materials and mechanical seals for extreme loads and long-lasting, low-wear components (Figure 5). However, the costs of machining to achieve the necessary tight tolerances have presented a barrier to widespread use in bearings and seals up to now. To achieve broader use in such applications, further improvements in effective machining are necessary. In particular, laser-based machining of these materials offers prospects for overcoming this barrier.

The future of cost-effective diamond composites

As demand grows for cost-effective, wear-resistant materials with a long service life and thermal management systems with extremely high thermal conductivity, so too grows the need for cost-effective diamond materials. The diamond–SiC composites described in this article can be a solution to this need.

The findings obtained so far form a solid basis for producing components as prototypes or in small batches with the potential to further improve the existing exceptional properties or tailor them to special needs. For applications with low tolerance requirements, such as sandblasting nozzles and mill components, these materials are already a cost-effective alternative to existing materials. However, to improve the market potential of these materials for applications with strict tolerance requirements, such as bearings and seals, processes based on laser and spark erosion are currently being developed.

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Exploring microgravity manufacturing on the Starlab commercial space station

By Jonathan Volk



As manufacturers push for higher-performing reliable materials and greater production precision, researchers and industrial developers are increasingly exploring how space-based manufacturing can support materials processing.

On Earth, manufacturing processes are influenced by gravity-driven effects, such as buoyancy, convection, and sedimentation, which make accomplishing uniform production of certain materials extremely difficult or impossible. But in low Earth orbit (LEO), scientists can study crystal growth, microstructure formation, phase transitions, fluid dynamics, and thermal behavior without many of these gravity-driven effects—thus gaining a better understanding of how materials form, how defects develop, and how manufacturing processes can be optimized for high-performance industrial applications.

Some companies have used this increased understanding to demonstrate the production of commercial materials on the International Space Station (ISS). For example, California-

based United Semiconductors grew multiple semimetal semiconductor ingots on the ISS in early 2025, resulting in more than 90% product yield compared to less than 5% yield on Earth for the same material. The company launched a follow-on demonstration to the ISS in May 2026.¹ Connecticut-based LambdaVision, a company focused on retinal implant manufacturing to cure macular degeneration and retinitis pigmentosa, has flown nine payloads to the ISS over the last decade. Their experiments proved the need for microgravity to manufacture the layered proteins required for these critical medical devices.²

Despite these budding commercial successes, the ISS is officially scheduled to retire within the next few years. Its decommissioning will leave a need for new platforms that can further enable microgravity testing and manufacturing at scale.

Starlab Space (Webster, Texas) is developing a commercial LEO platform to support long-duration space-based research, testing, and manufacturing activities of advanced materials. By providing access to a persistent microgravity environment, the company aims to help industrial users study manufacturing challenges that are difficult to isolate in terrestrial laboratories and be able to manufacture next-generation materials in space.

Starlab: A new approach to microgravity research and manufacturing

Starlab Space is a U.S.-led joint venture involving Voyager Technologies, Airbus, Mitsubishi Corporation, MDA Space, Palantir Technologies, and Space Applications Services. Its strategic partners include Northrop Grumman, Journey, Hilton, and The Ohio State University.

The Starlab commercial space station, which is scheduled to launch in 2029, will provide researchers and industrial users with continued access to a human-tended microgravity laboratory environment and in-space manufacturing platforms, the latter of which the ISS was never designed to support. It will also incorporate artificial intelligence capabilities to support research and industrial activities in LEO.

The station's heightened commercial focus is intended to give users more consistent opportunities to conduct iterative testing, materials characterization, and long-duration manufacturing research activities in orbit. It will also include ample dedicated spaces for industrial users to develop next-generation products at scale (Figure 1). These spaces include areas both internally on Starlab and on attached external platforms that can utilize the pure vacuum environment of space.

In addition to determining which materials may benefit from microgravity processing, researchers and industrial users can also harness the station's capabilities to determine which steps of the manufacturing process are not significantly affected by gravity. By uncovering this nuance, they can perform just those critically impacted manufacturing steps in space and complete the other steps on Earth, where it is more cost effective.

Glass and ceramic manufacturing in space

Glass and ceramic materials are among the manufacturing projects already being explored in microgravity environments.

Regarding glass materials, ZBLAN optical fiber production is a main example. On Earth, gravity-driven manufacturing processes can introduce imperfections into an optical fiber. In microgravity, manufacturers may be able to produce longer, higher-quality optical fibers with improved performance, most notably significantly reduced signal attenuation. In a study conducted on the ISS in 2024, California-based advanced manufacturing company Flawless Photonics pulled a more than 1 km homogeneous fiber of the fluoride-based ZBLAN in a single test and produced more than 11 km in total over the test sequence.³

On the ceramics side, Florida-based aerospace manufacturer Redwire produced a series of ceramic turbine blisks on the ISS to demonstrate that critical ceramic parts could be made in space with a higher quality than those made on Earth.⁴ Key material properties of the stereolithography-produced blisks include higher fatigue strength and lower residual stress.

Space-based manufacturing is not only about producing materials in orbit for use on Earth. As public and private space missions expand, demand will grow for materials produced in space for in-space use. On-demand production could reduce reliance on resupply missions while shortening production and delivery timelines. Starlab aims to support the development of these types of in-space manufacturing applications.



Figure 1. A rendering of the research and manufacturing spaces on board the planned Starlab space station.

Expanding the manufacturing toolbox for space-based operations

The demand across numerous industries for manufacturing capabilities in a microgravity environment is at an all-time high. As more examples of materials and products that cannot be produced on Earth are announced, microgravity environments have become increasingly viewed as a valuable tool for advanced manufacturing and materials processing.

There needs to be more state-of-the-art infrastructure in LEO to support both research and manufacturing of novel industrial materials, including ceramics and glasses. The Starlab station will be positioned as one of the premier platforms in LEO for next-generation materials development and manufacturing innovation, benefiting life both on Earth and in space.

Starlab Space is currently engaging with interested customers of all types (industry, academia, government) who wish to conduct research and/or manufacturing in microgravity and, eventually, on the Starlab station. Learn more about the planned Starlab LEO platform at <https://starlab-space.com>. Email the author if you would like to discuss how your organization can become a user of the Starlab commercial space station.

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Aerospace maintenance: The need for improved understanding of interfacial failure

By Shree Nagarkar and Wesley Drew Frey

Since the mid-20th century, aerospace structures have been increasingly defined not by bolts and rivets but by bonds.

Thin interfacial joining layers—including polymeric adhesives, glass solders, and other ceramic and metallic joining materials—enable lightweight assembly of structural components while also reducing stress concentrations associated with mechanical fasteners. From fuselages to control surfaces in both military and commercial aircraft, a wide range of interfacial joining technologies—including adhesive bonding, soldering, and brazing—are integral to structural performance and efficiency of vehicles in this sector.^{1,2}

Yet with these benefits comes the challenge of detecting failure in the joined surface. Unlike cracks in mechanically fastened joints, which can often be identified and monitored more directly, failure within an interface is difficult to observe. In high-performance aircraft operating under cyclic loads and high-stress environments—and regularly past their original design life³—these boundary regions can degrade silently, raising important questions about proper diagnosis and maintenance to ensure safe, long-term operation.

Mechanics of and challenges with modeling interfacial failure

Unlike fracture in metallic mechanical fasteners, which typically is dominated by crack-tip stress concentrations within the bulk material, failure in interfacially joined materials is governed by both normal and shear tractions at the interface (commonly referred to as mixed-mode loading). The response of the joined interface depends not only on the applied loads but also on material properties, surface preparation, bond quality, and geometric configuration.^{1,2}

To model such behavior, engineers often rely on cohesive zone models, which represent the interface as a region that can progressively degrade and separate under loading.⁴ These models are effective at capturing failure in simplified test cases, such as double cantilever beam and end-notched flexure speci-

mens (Figure 1).^{4,5} However, transitioning from these idealized configurations to real-world geometries is challenging for a couple reasons. One, small changes in overlap length, joining material thickness, or boundary conditions can significantly alter the stress distribution and, consequently, the predicted failure response. Two, more complex joint configurations—such as single-lap joints, stepped interfaces, and tongue-and-groove connections—introduce coupled multiaxial loading, secondary bending, geometric discontinuities, and mixed-mode interfacial stresses.^{6,7} These additional parameters make such configurations much more difficult to model and accurately validate.

These challenges highlight the core concern: Our ability to simulate interfacial failure is often limited by the assumptions embedded in our models.

Seeing the invisible: Advances in imaging techniques

To improve predictive modeling approaches, greater insight into the physical mechanisms at the joined interface is needed. However, as noted before, interfaces are typically hidden from view. Traditional inspection techniques, such as visual inspection and ultrasonic testing, provide limited insight into how and where failure initiates and propagates. Fortunately, recent imaging advances are beginning to change this landscape.

Nondestructive evaluation techniques such as X-ray computed tomography and neutron radiography allow researchers to visualize internal damage and failure progression within interfacially joined structures.^{8,9} By combining such imaging methods with mechanical testing, researchers can uncover the mechanics of interfacial failure under load—offering a rare glimpse into processes previously inferred only indirectly.

Bridging modeling, imaging, and mechanical testing

Although there is much potential to improve the detection of interfacial failure in aerospace structures through experimentally optimized simulations, several obstacles stand in the way of accomplishing this objective.

First, the suitability of a particular imaging technique depends strongly on the materials being joined. X-ray-based

methods are widely used for evaluating defects in denser materials, such as metals, ceramics, and glasses in soldered or brazed joints. However, the polymeric adhesives commonly used in legacy and modern aerospace structures often provide limited X-ray contrast, especially when confined between metallic adherends.

While contrast-enhanced adhesive systems and advanced X-ray techniques can improve detectability, characterization of thin polymeric adhesive layers and their early-stage interfacial failure remains challenging. In such cases, neutron imaging offers a complementary capability because of its sensitivity to hydrogen-rich materials, such as polymeric adhesives, which can be visualized even when enclosed by metallic components. Despite this advantage, the application of neutron radiography for the characterization of polymeric adhesive bondlines and interfacial failure in aerospace structures remains relatively understudied.

Regarding the integration of experimental observations with simulations, existing studies have demonstrated partial integration using finite element modeling, full-field measurements, and post-failure imaging.^{4–9} However, the integration of neutron-based internal failure visualizations with cohesive-zone-based predictive modeling remains insufficiently researched.

If we can fill these gaps in the literature, the resulting integrated approaches may contribute to the development of more adaptive predictive frameworks for interfacially joined structures, enabling improved structural health assessment and damage-informed maintenance strategies.

The future of aerospace maintenance

Interfacial joining methods have enabled a new generation of aerospace design, but their adoption means unseen interfaces are now the weakest link in the structure. To ensure that interfacially joined components perform reliably over the course of their operational life, future research in this field will need to focus on

- Improved multiscale modeling approaches,
- Data-driven methods for parameter identification,
- Advanced imaging methods for real-time monitoring, and
- Integration of simulation and inspection into unified frameworks.

Ultimately, deciphering the behavior of joined interfaces is not merely a question of materials science or mechanics—it is a multidisciplinary challenge at the intersection of modeling, experimentation, and engineering practice. As we continue to push the limits of performance and efficiency, learning how—and why—these interfaces fail may prove to be just as important as designing them in the first place.

About the authors

Shree Nagarkar is a Ph.D. candidate at the University of California, Davis, working with Professor Subhash Risbud and

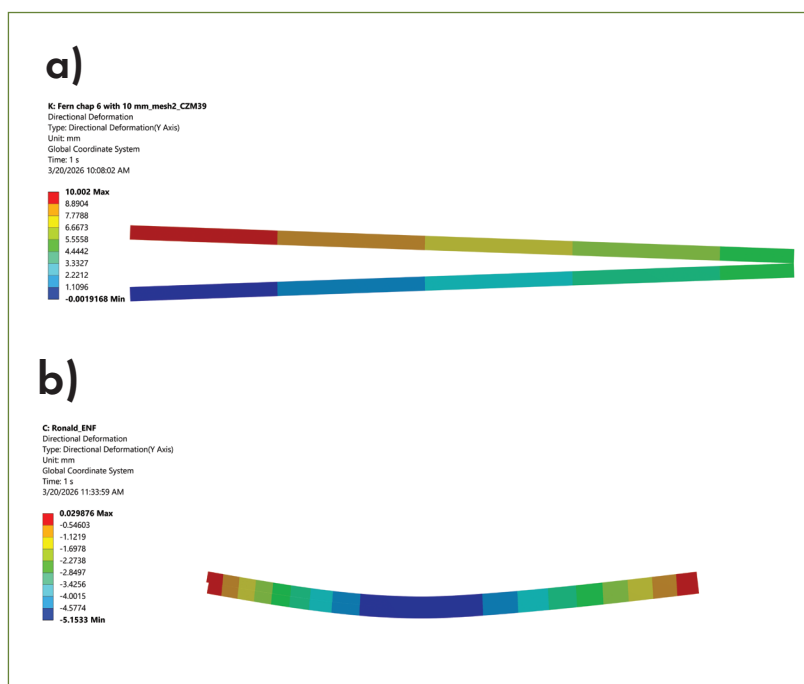


Figure 1. Example of cohesive zone models representing failure in (a) double cantilever beam and (b) end-notched flexure specimens.

McClellan Nuclear Research Center Director Wesley Drew Frey. Contact Nagarkar at bsnagarkar@ucdavis.edu and Frey at wesfrey@ucdavis.edu.

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*All references verified as of June 12, 2026. ■

LEGEND: A red circle ● denotes a new event in this issue. A star ★ denotes an ACerS short course.

August 2026

● ★ ACERS COURSE

19 Applications of Ceramic Processing to the Development of UHTC Materials – Golden, Colo.; <https://ceramics.org/course/applications-ceramic-processing-development-uhtc-materials>

ENDORSED EVENT

31–Sept. 1 The International Conference on Sintering – Eurogress Aachen, Aachen, Germany; <https://www.sintering2026.org/en>

September 2026

ENDORSED EVENT

6–11 11th International Congress on Ceramics – Sapporo Convention Center, Sapporo, Japan; <https://www.ceramic.or.jp/icc11>

★ ACERS COURSE

14–15 Tools for Visualizing and Understanding the Structure of Crystalline Ceramics – Virtual <https://ceramics.org/course/sparks-crystalline-ceramics>

● ★ ACERS COURSE

15–Dec. 10 Refractory Fundamentals – Virtual; <https://ceramics.org/course/homeny-refractory-fundamentals>

● ★ ACERS COURSE

22–Oct. 1 Sintering of Ceramics – Virtual; <https://ceramics.org/course/castro-sintering-course>

● ★ ACERS COURSE

29 Thermal Measurement Workshop – Columbus, Ohio; <https://ceramics.org/course/thermal-measurement-workshop-2026>

ENDORSED EVENT

29–Oct. 1 International Thermal Conductivity Conference and International Thermal Expansion Symposium 2026 – Renaissance Columbus Westerville-Polaris Hotel, Westerville, Ohio; <https://ceramics.org/itcc2026>

October 2026

ACERS EVENT

4–7 ACerS 128th Annual Meeting with Materials Science and Technology 2026 – David L. Lawrence Convention Center, Pittsburgh, Pa.; <https://ceramics.org/annual-meeting2026>

● ★ ACERS COURSE

13–22 Practical AI and Machine Learning for Materials Science – Virtual; <https://ceramics.org/course/sparks-practical-ai-machine-learning>

November 2026

● ★ ACERS COURSE

3–4 Ceramic Matrix Composites and Joining of Dissimilar Materials – Virtual; <https://ceramics.org/course/cmc-joining-materials>

January 2027

ACERS EVENT

24–29 51st International Conference and Expo on Advanced Ceramics and Composites – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; <https://ceramics.org/icacc2027>

May 2027

● ACERS EVENT

23–28 ACerS Spring Meeting 2027 – Hilton San Francisco Union Square, San Francisco, Calif.; <https://ceramics.org/acersspring2027>

June 2027

● ENDORSED EVENT

20–24 16th International Conference on the Structure of Non-Crystalline Materials – Embassy Suites Boulder and Hilton Garden Inn Boulder, Boulder, Colo.; <https://ceramics.org/ncm16>

October 2027

● ACERS EVENT

24–27 ACerS 129th Annual Meeting with Materials Science and Technology 2027 – David L. Lawrence Convention Center, Pittsburgh, Pa.; <https://ceramics.org/annualmeeting2027>

'STEEL'ING A LOOK AT NONFERROUS APPLICATIONS DURING THE 61ST ANNUAL SYMPOSIUM ON REFRACTORIES

All photos credit: ACerS

The market for nonferrous metals is growing rapidly in response to the electrification, renewable energy, and digital transformations. Processing these metals comes with unique challenges compared to the iron and steel industry, and this year's 61st Annual Symposium on Refractories shed light on some of these difficulties and offered possible solutions.

The ACerS Greater Missouri Section and Refractory Ceramics Division co-hosted the Annual Symposium, which welcomed more than 190 attendees from 15 countries to St. Louis from March 30–April 1, 2026. Kimberley Peterson of Christy Refractories and Dan Gower of Refractory Minerals Co. co-programmed the event, which served as an opportunity for both valuable knowledge sharing and networking.

THE MULTIFACETED CHALLENGES OF NONFERROUS METALS PRODUCTION

Before solutions could be offered, many of this year's talks focused on outlining the challenges

that come with nonferrous metals production. In particular, weakening of the refractory's mechanical properties is a perennial concern, be that from corrosion or other factors.

For example, Roger Smith of Plibrico Company kicked off the symposium by reviewing causes of corundum formation in aluminum melting furnaces. Chemical reactions between the molten metal and aluminosilicate refractories will cause corundum to form on furnace walls, doors, and burners. Over time, this expansive growth reduces furnace capacity, increases energy consumption, and causes premature refractory failure.

Smith discussed the factors that can promote or exacerbate corundum growth, specifically high temperature, presence of oxygen, alloy composition, and the use of fluxes and fluoride salts. He then suggested ways to fight this formation, including the use of nonwetting additives, dense oxide barrier formers, pore size reducers, and physically removing the growth.

Following talks went into more detail on the refractories themselves, such as the development of silica-free refractories to mitigate corundum growth in aluminum furnaces as well as to better withstand hydrogen-fired operations. Refractories for the copper industry also had their moment when Somnath Mandal of Vesuvius talked about the development of chromium-free refractories to avoid the formation of carcinogenic hexavalent chromium.

The development of novel and alternative binders for refractories also received a fair amount of attention, with the aim of reducing reliance on calcium aluminate cement prompting many studies. This common high-performance hydraulic binder can suffer from several technical problems, such as reduced strength due to the formation of undesirable hydration products during curing and a potential for explosive spalling during the first heating. Several speakers discussed the potential of phosphate binders for nonferrous applications, with varying results based on the specific application.

ADDRESSING REFRACTORY CHALLENGES THROUGH INVENTION AND INNOVATION

While identifying and developing solutions to known problems is a first step, manufacturers must successfully implement and commercialize that idea to add value to their processes. How companies can accomplish this task was the focus of this year's Theodore J. Planje Refractories Award lecture, delivered by Tomas Richter of MaterialsPro Technologies LLC.

Many of the talks on Wednesday, April 1, provided real-world examples of putting Richter's suggestions into practice. For example, Paschoal Bonadia of Bautek Minerais Industriais discussed the development of high-performance sintered bauxite and high-purity brown fused alumina using Brazilian sources at Barro Alto as an alternative to China's grasp on the market. Similarly, Gibran Sánchez of Pyrotek talked about Mexico's reliance on other countries for many raw materials and the need for fast testing methods to screen alternative formulations, in this case noncontact dilatometry.

See more photos from the 61st Annual Symposium on Refractories on the ACerS Flickr page at <https://bit.ly/Refractories-Symposium-2026>. The 62nd Annual Symposium on Refractories will take place in March 2027. ■



ACerS Fellow Nancy E. Bunt of Imerys, right, presents Tomas Richter with the 2026 Theodore J. Planje Refractories Award.



The 61st Annual Symposium on Refractories began with a social event on Monday evening at Westport Social.

'WE ARE ALL CONNECTED' AT THE NEW SIX-DIVISION SPRING MEETING 2026

All photos credit: ACerS

When Edward Orton, Jr. and his colleagues founded The American Ceramic Society in 1898, the technical study of ceramics to address the practical needs of industry was a novel concept. Yet as the benefits of such studies became more apparent to manufacturers, the Society's membership grew and became more specialized, leading to the creation of professional divisions in 1919.

Although some members feared that the creation of divisions would cause the Society to split apart, Orton wrote confidently in an early report that "the Society is not to be divided physically into sections meeting in different places, but that the division is a sort of intangible one ... to stir up debates, papers and program material—in other words, to build off the work of the Society, each in his own field."

Over the next hundred years, new divisions were created and others metamorphosed as science and industry advanced. As of today, 11 Divisions represent the diverse interests and research areas of ACerS members, ranging from traditional structural and processing applications to advanced electronic and biomedical devices.

This spring, six Divisions joined hands to launch a new chapter in ACerS history with the inaugural Spring Meeting. This meeting, which took place April 12–17, 2026, in Bellevue, Wash., is a new venture for the Society that is not to be confused with ACerS Annual Meeting, which takes place in the fall. Instead, Spring Meeting is a Division-focused event that gives the six participating Divisions an opportunity to host their usual Division meeting agendas alongside jointly organized events and symposia. It is thus a prime example of Orton's dream, whereby specialized scientists and engineers work together collaboratively to advance ceramic and glass science and technology.

Nearly 670 attendees from 29 countries, including 245 students, participated in the inaugural Spring Meeting. The six Divisions involved are Basic Science, Bioceramics, Electronics, Energy Materials and Systems, Glass & Optical Materials, and Manufacturing.

ACerS President Mario Affatigato says, "The new Spring Meeting fulfilled every expectation by providing an amazing, multidisciplinary arena for the exchange of scientific ideas and the formation of new friendships and collaborations. I very much look forward to an even larger and more exciting conference next year!"

Conference Chair Rajendra Bordia echoed his sentiments, saying, "Due to the vision, leadership, and hard work of the volunteer leaders and ACerS staff, this first-ever Spring Meeting of ACerS was a resounding success that achieved the twin goals—technical programming that is true to the needs of the participating Divisions' Divisional meetings, including joint Divisional programming where appropriate, and a forum where a large community of ceramic scientists and engineers could network and connect with friends and colleagues."

PLENARY TALKS WELCOME SPEAKERS FROM ALL SIX DIVISIONS

From Monday through Wednesday of the conference, each morning started with two plenary talks given by a representative from each of the six Divisions.

On Monday, Basic Science Division speaker Elizabeth Dickey of Carnegie Mellon University discussed the role of defects in tuning the electrical properties of ceramics. She was followed by Electronics Division speaker Eric Wachsman of the Maryland Energy Innovation Institute, who talked about how his company ION Storage Systems is developing lithium-based solid-state batteries.

On Tuesday, Energy Materials and Systems Division speaker Maarit Karppinen of Aalto University shared her research on thin-film materials created using atomic layer and molecular layer deposition, with the former technique being created by another professor at her university. Glass & Optical Materials Division speaker Srikanth Sastry of Jawaharlal Nehru Centre for Advanced Scientific Research then spoke about using machine learning to help model fatigue failure behavior in sheared glasses.

On Wednesday, Manufacturing Division speaker William Carty of Alfred University gave an overview of ceramic processing, a topic that he will elaborate on further during an upcoming ACerS short course.

Bioceramics Division speaker Candan Tamerler of the University of Kansas then gave a thorough rundown of the evolution of biomaterials from bioinert to biofunctional, with acknowledgments to Larry Hench and Rustum Roy for their impact on this field.

DIVISION AWARD LECTURES RECOGNIZE LUMINARIES IN THEIR FIELDS

Several Division award lectures were delivered at Spring Meeting, with each recognizing important topics of discussion in the ceramics and glass field today.

On Monday, Jon-Paul Maria of The Pennsylvania State University delivered the Basic Science Sosman Award lecture on the topic of ferroelectrics. Both he and plenary speaker Dickey earlier that morning expressed excitement about once again attending an ACerS meeting in the spring. (The ACerS Annual Meeting used to be held in the spring before being moved to the fall.)

On Wednesday, Daniel Schwoerer of Bullseye Glass Co. delivered the Stookey Lecture of Discovery on his company's unique process of creating hand-cast multicolored glass. The technique has been used to help create some well-known global pieces, including the United Methodist Church of the Resurrection stained-glass window in Leawood, Kan.

On Thursday, Timothy Gross of Corning Inc. delivered the Varshneya Frontiers of Glass Technology Lecture on the design of damage-resistant glasses. He discussed several techniques for doing so, with examples pulled from his experience at Corning.

Besides the award lectures, several other Division awards were handed out at Spring Meeting. A summary of those awards can be found on page 16.

ROUNDTABLE DISCUSSION ON THE RESILIENCE OF US RESEARCH

The state of federal science funding in the United States has been a topic of great concern over the past two years. Considering this concern, a roundtable discussion took place on Tuesday to discuss the resilience of U.S. research. Reeya Jayan of Carnegie Mellon University moderated the discussion, which included ACerS President Mario Affatigato, Christina

Rost of Virginia Tech, and Rost's student John Barber as panelists. Postdoctoral fellow Kartik Nemani published a reflection on the event in the June/July *Bulletin* (page 42).

The roundtable generated so much interest that a webinar continuing the discussion was held in June 2026. The webinar recording can be accessed at <https://ceramics.org/course/the-resilience-of-us-research>.

NEW COMPETITIONS PROVIDE ADDITIONAL OPPORTUNITIES FOR STUDENTS

ACerS meetings are always filled with various student-oriented events, including the Basic Science and Manufacturing Divisions tutorials that previ-

ously took place at the now-retired Electronic Materials and Applications Conference. Spring Meeting 2026 welcomed two new additions to the student roster, specifically a glass design competition and poster competition.

The Glass Strengthening Competition, organized by the Ceramic and Glass Industry Foundation, challenged participants to strengthen identical glass samples using different strengthening techniques. They then brought the strengthened samples, which were prepared prior to the conference, and competed to see whose sample performed best during on-site impact testing. Learn more about the competition in the June/July 2026 *Bulletin* (page 43).

The Edwin Fuller Student Poster Competition celebrates outstanding student research in ceramic and glass science and engineering while honoring the remarkable career and contributions of the late Edwin H. Fuller, an ACerS Distinguished Life Member, past Society president, and respected industry leader. Fuller's wife, Barbara, attended Spring Meeting to present the students with their awards. The list of all award winners can be found on page 17.

View more images from the conference on ACerS Flickr page at <https://bit.ly/Spring-Meeting-2026>. Spring Meeting 2027 will take place May 23–28, 2027, in San Francisco, Calif. ■



An attendee helps color in a poster celebrating the “We are all connected” theme of Spring Meeting 2026.



ACerS President Mario Affatigato, right, presents Rajendra Bordia with a certificate of appreciation for his work organizing the inaugural Spring Meeting.



Besides the Division award lectures, a special symposium took place on Wednesday and Thursday in honor of ACerS Fellow Steve Feller, who died in November 2025. Moderating the symposium was ACerS President Mario Affatigato (pictured), a long-time student, colleague, and friend of Feller's at Coe College (Cedar Rapids, Iowa).



Barbara Fuller, second from right, stands with two winners of the Edwin Fuller Student Poster Competition as well as Richard Brow, second from left, who announced the award.

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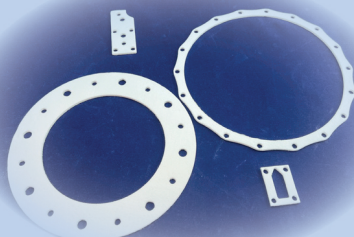
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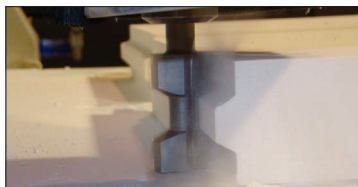
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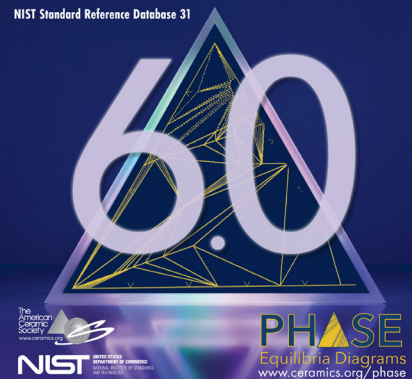
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Additive manufacturing of novel hydrogel feedstocks for aerospace applications

The aerospace industry relies on highly specialized, custom-engineered components that can withstand extreme environments. Traditionally, manufacturing these parts requires complex tooling, expensive molds, and intricate, multistep supply chains, which are susceptible to global disruptions. However, the emerging field of additive manufacturing offers a resilient solution to these production challenges by allowing parts to be manufactured on demand and without the need for traditional molds and machine tooling.

Among the various AM techniques, robocasting involves extruding a thick paste called the feedstock from a syringe into layers that are stacked and fused together to create a solid part. This technique is advantageous for prototyping and decentralized manufacturing purposes because no molds are necessary, thus allowing samples to be made quickly and easily.¹

At Alfred University, the research group of Junjun Ding, including myself, has investigated different methods of creating robocasting feedstocks, with a recent focus on using thermoresponsive hydrogels as the base material. Thermoresponsive hydrogels, in this case Pluronic F-127, are a unique type of hydrogels that behave as liquids when chilled but turn into solid gels at room temperature and above (similar to the texture of aloe).

This temperature-dependent phase transition involves hydrogen bond cross linking, in which the unlinked hydrogel strands form small clusters that lock-in with one another. The thermal reactivity of these hydrogels makes them strong candidates for ceramic AM because temperature control can be used to make the material extrusion easier at a lower temperature. Additionally, their thermal reactivity means that very little organic material, which is typically added to help make feedstock extrudable, is needed.

In our latest study, which is now being prepared for journal publication, we found that the composition remains stable and uniform for at least three weeks when stored in an airtight container. This stability allows for flexibility with printing because you do not need to process the material immediately after mixing. From a resilient manufacturing perspective, this behavior is a massive advantage by allowing quick and easy ceramic 3D printing using shelf-stable feedstocks.

Various ceramic powders can be mixed into the hydrogel to form a feedstock. For example, silicon carbide (SiC) is an ultrahigh-temperature ceramic with a very high maximum load strength (79,000 lb/in²). These properties make SiC a good material choice for the aerospace industry.

The SiC-filled hydrogel can be made even stronger by including fibrous materials in the feedstock. In particular, ceramic whiskers are a type of highly pure and uniform fibrous

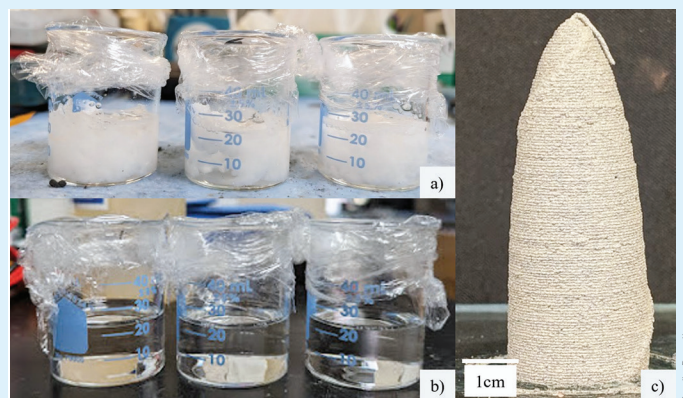


Figure 1. Pictures showing (a) hydrogel solution after adding the copolymer Pluronic F-127 to water and (b) the result of chilling for 24 hours, which allows full dissolution of the powder into liquid. (c) 3D-printed scale model of a nosecone using the SiC-filled hydrogel feedstock.

nanoscale filament that can greatly strengthen the feedstock because of how they align while being extruded. Initially after mixing, the whiskers are in a random alignment, but they align parallel to the extrusion direction as the feedstock exits the syringe tip. When aligned in this way, breakage is reduced because the whiskers create paths for cracks to disperse energy instead of propagating through the part.²

By using robocasting to print SiC-SiC hydrogel composites, parts for aerospace applications can be rapidly produced with increased mechanical strength and high working temperature (Figure 1). These parts are especially suited for use on the leading edges and nosecones of high-speed flight vehicles, and scale models can be created and tested in controlled environments to assess their properties, such as their heat resistance and strength, before building full-size versions for real-world use.

By creating a 3D-printable ceramic feedstock with a long shelf life, we are helping pave the way to faster, more adaptable, and highly resilient aerospace manufacturing.

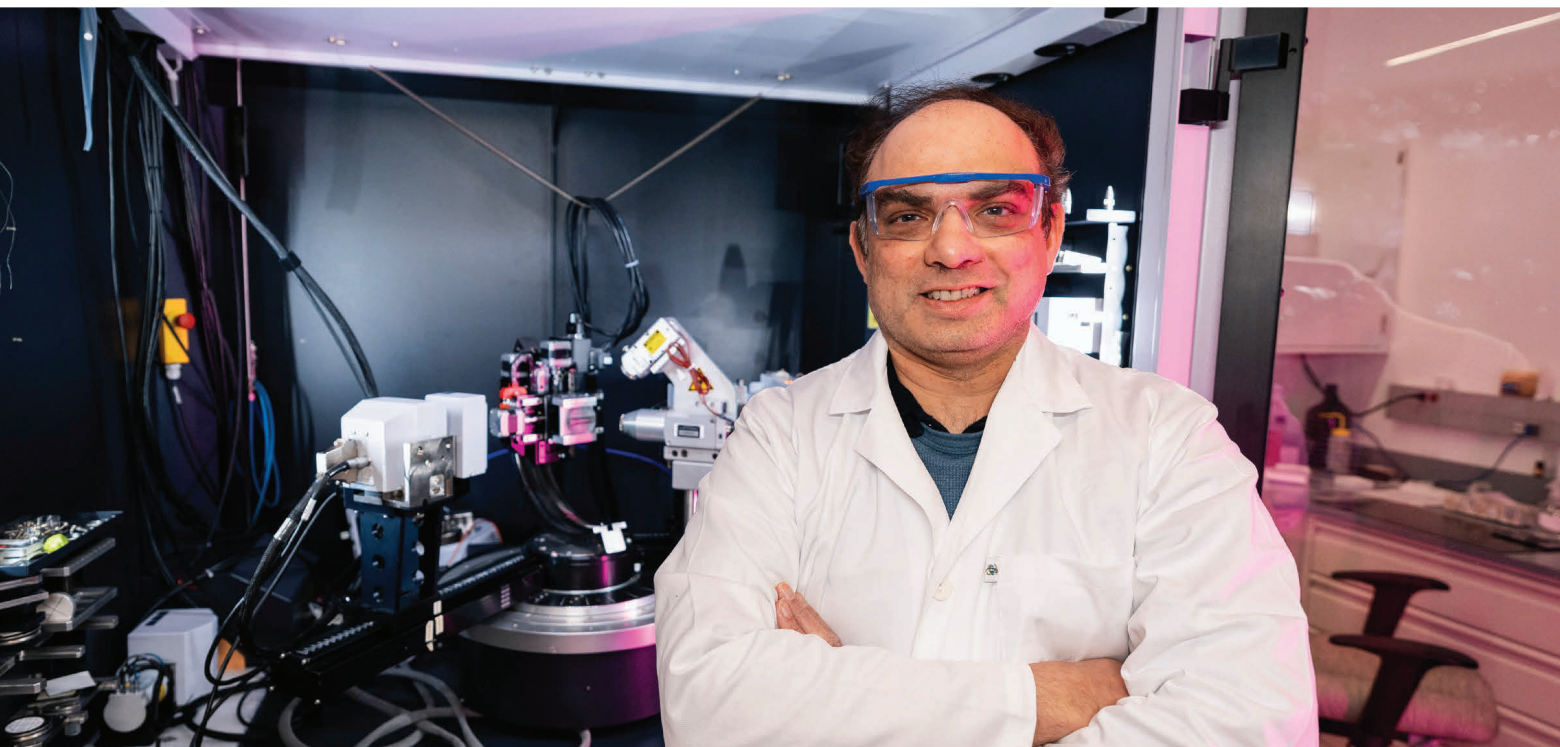
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Anthony Brandl is a master's candidate at Alfred University. The primary focus of his research involves the development of ceramic hydrogel feedstocks intended for aerospace applications. Outside of the laboratory, Anthony enjoys camping, cooking, and running. ■

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Dr. Abhijit Pramanick's research interests include design, synthesis and multiscale structure-property characterization of functional oxides, with an emphasis on ferroelectric and piezoelectric ceramics that are used in high-power energy storage, electromechanical sensors/actuators, energy harvesting and solid-state cooling devices. At Alfred University, he is looking forward to building a research program on processing-structure-property characterization of new kinds of functional ceramics, including 3-D printed metamaterials and grain-oriented ceramics.



Abhijit Pramanick obtained his Ph.D. in Materials Science and Engineering in 2009 from the University of Florida, Gainesville. After his Ph.D., he held postdoctoral appointments at Alfred University and Oak Ridge National Laboratory, where he worked on the applications of different X-ray and neutron scattering techniques to understand the microscopic origins of functional responses in ferroelectric and ferromagnetic materials. From 2015-2023, he served as an Assistant Professor in the Department of Materials Science and Engineering at the City University of Hong Kong. In 2023, he joined University Paris-Saclay as a Senior Jean D'Alembert Fellow, where he developed methodology for quantitative structure-property characterization of 3-D printed architected piezoceramics using X-ray microdiffraction and micromechanical computations. Dr. Pramanick has coauthored more than 65 peer-reviewed publications. For his work on in situ structural characterization using X-ray diffraction, he was awarded the Edward C. Henry Award by the American Ceramic Society in the years 2010 and 2012. During his stay at the Oak Ridge National Laboratory, Dr. Pramanick served as co-investigator on a Laboratory Director's Research and Development fund. He has also been awarded numerous research grants from the Research Grants Council of Hong Kong and the Innovation and Technology Commission of Hong Kong.

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21 Sc 44.955912 Scandium	22 Ti 47.867 Titanium
23 V 50.9415 Vanadium	24 Cr 51.9961 Chromium
25 Mn 54.938045 Manganese	26 Fe 55.845 Iron
27 Co 58.933195 Cobalt	28 Ni 58.6934 Nickel
29 Cu 63.546 Copper	30 Zn 65.38 Zinc
31 Ga 69.723 Gallium	32 Ge 72.64 Germanium
33 As 74.9216 Arsenic	34 Se 78.96 Selenium
35 Br 79.904 Bromine	36 Kr 83.798 Krypton
37 Rb 85.478 Rubidium	38 Sr 87.62 Strontium
39 Y 88.90585 Yttrium	40 Zr 91.224 Zirconium
41 Nb 92.90638 Niobium	42 Mo 95.96 Molybdenum
43 Tc (98.9062) Technetium	44 Ru 101.07 Ruthenium
45 Rh 102.9055 Rhodium	46 Pd 106.42 Palladium
47 Ag 107.8682 Silver	48 Cd 112.411 Cadmium
49 In 114.818 Indium	50 Sn 118.71 Tin
51 Sb 121.76 Antimony	52 Te 127.6 Tellurium
53 I 126.90447 Iodine	54 Xe 131.29 Xenon
55 Cs 132.9054 Cesium	56 Ba 137.327 Barium
57 La 138.90547 Lanthanum	58 Ce 140.90768 Cerium
59 Pr 140.90768 Praseodymium	60 Nd 144.242 Neodymium
61 Pm (144.9128) Promethium	62 Sm 150.36 Samarium
63 Eu 151.964 Europium	64 Gd 157.25 Gadolinium
65 Tb 158.92535 Terbium	66 Dy 162.5 Dysprosium
67 Ho 164.93032 Holmium	68 Er 167.259 Erbium
69 Tm 168.93041 Thulium	70 Yb 173.054 Ytterbium
71 Lu 174.967 Lutetium	72 Hf 178.49 Hafnium
73 Ta 180.94788 Tantalum	74 W 183.84 Tungsten
75 Re 186.207 Rhenium	76 Os 190.23 Osmium
77 Ir 192.222 Iridium	78 Pt 195.084 Platinum
79 Au 196.966569 Gold	80 Hg 200.59 Mercury
81 Tl 204.3833 Thallium	82 Pb 207.2 Lead
83 Bi 208.9804 Bismuth	84 Po (209) Polonium
85 At (210) Astatine	86 Rn (222) Radon
87 Fr (223) Francium	88 Ra (226) Radium
89 Ac (227) Actinium	90 Th 232.0377 Thorium
91 Pa 231.03688 Protactinium	92 U 238.02891 Uranium
93 Np 237.048173 Neptunium	94 Pu 244.064224 Plutonium
95 Am (243) Americium	96 Cm (247) Curium
97 Bk (247) Berkelium	98 Cf (251) Californium
99 Es (252) Einsteinium	100 Fm (257) Fermium
101 Md (258) Mendelevium	102 No (259) Nobelium
103 Lr (262) Lawrencium	104 Rf (261) Rutherfordium
105 Db (262) Dubnium	106 Sg (266) Seaborgium
107 Bh (264) Bohrium	108 Hs (277) Hassium
109 Mt (268) Meitnerium	110 Ds (271) Darmstadtium
111 Rg (272) Roentgenium	112 Cn (285) Copernicium
113 Nh (284) Nihonium	114 Fl (289) Flerovium
115 Mc (290) Moscovium	116 Lv (293) Livermorium
117 Ts (294) Tennessine	118 Og (294) Oganesson

58 Ce 140.116 Cerium	59 Pr 140.90768 Praseodymium	60 Nd 144.242 Neodymium	61 Pm (144.9128) Promethium	62 Sm 150.36 Samarium	63 Eu 151.964 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.92535 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.93032 Holmium	68 Er 167.259 Erbium	69 Tm 168.93041 Thulium	70 Yb 173.054 Ytterbium	71 Lu 174.967 Lutetium
90 Th 232.0377 Thorium	91 Pa 231.03688 Protactinium	92 U 238.02891 Uranium	93 Np 237.048173 Neptunium	94 Pu 244.064224 Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (247) Berkelium	98 Cf (251) Californium	99 Es (252) Einsteinium	100 Fm (257) Fermium	101 Md (258) Mendelevium	102 No (259) Nobelium	103 Lr (262) Lawrencium

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